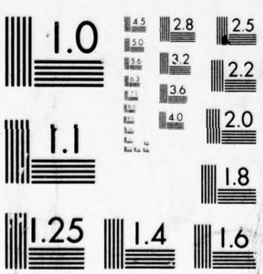
AD-A031 046 CIVIL ENGINEERING LAB (NAVY) PORT HUENEME CALIF F/G 13/13
EXPERIMENTAL POLYURETHANE FOAM ROOFING SYSTEMS.(U)
AUG 76 J R KEETON, R L ALUMBAUGH, E F HUMM

UNCLASSIFIED CEL-TN-1450 NL

1 OF 2
AD
A031046

1 OF 2

AD
A031046



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Technical Note N-1450

EXPERIMENTAL POLYURETHANE FOAM ROOFING SYSTEMS

By

John R. Keeton, Robert L. Alumbaugh, Ph D,
and Edwin F. Humm

August 1976

Sponsored by

NAVAL FACILITIES ENGINEERING COMMAND

Approved for public release; distribution unlimited.

CIVIL ENGINEERING LABORATORY
Naval Construction Battalion Center
Port Hueneme, California 93043

Mr. John R. Keeton and Dr. Robert L. Alumbaugh are staff members of the Civil Engineering Laboratory. Mr. Edwin F. Humm is with the Northern Division of the Naval Facilities Engineering Command at Philadelphia, Pennsylvania.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

14

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER CEL- TN-1450	2. GOVT ACCESSION NO. DN544221	3. RECIPIENT'S CATALOG NUMBER 9 Technical rept. Jan 73-Oct 75
4. TITLE (and Subtitle) 6 EXPERIMENTAL POLYURETHANE FOAM ROOFING SYSTEMS.		5. TYPE OF REPORT & PERIOD COVERED Not final; Jan 1973 - Oct 1975
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 John R. Keeton, Robert L. Alumbaugh, ~~Ph D, and~~ Edwin F. Humm		8. CONTRACT OR GRANT NUMBER(s) 16 YF53-534 17 YF53-534-007
9. PERFORMING ORGANIZATION NAME AND ADDRESS CIVIL ENGINEERING LABORATORY Naval Construction Battalion Center Port Hueneme, California 93043		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62760N; YF53.534.007.01.011
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Facilities Engineering Command Alexandria, Virginia 22332		11 12. REPORT DATE August 1976
		13. NUMBER OF PAGES 95 12 102p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Urethane foam roofs, roofing, elastomeric coatings, energy conservation, heat transfer, roof repair, insulation.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An experimental roofing installation is described in which polyurethane foam is spray-applied to metal Butler-type roofs and then coated with five different elastomeric coatings. The coating systems included a catalyzed silicone rubber, a moisture-curing silicone rubber, a hypalon mastic, and two catalyzed butyl-hypalons. Temperatures are recorded on top of the foam, on the metal roof deck, and in the building attics, reveal the insulating

continued

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

391 111

bpg

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(*When Data Entered*)

20. Continued

quality of the foam. Fuel usage before and after application of the foam is included – a natural gas savings of 53% is indicated after foaming. The performance of each of the five coating systems over a 22-month period is summarized. Best overall performance was observed with the silicone rubbers; the poorest performance was with one of the catalyzed butyl-hypalons. Hail damage was observed on all of the coating systems except the silicones. Minor roof repairs that were done within the first year after installation are reported.

Library Card

Civil Engineering Laboratory
EXPERIMENTAL POLYURETHANE FOAM ROOFING SYSTEMS, by John R. Keeton, Robert L. Alumbaugh, Ph D, and Edwin F. Humm
TN-1450 95 pp illus August 1976 Unclassified

1. Roofing systems – elastomeric 2. Roof repair – urethane foam I. YF53.534.007.01.011

An experimental roofing installation is described in which polyurethane foam is spray-applied to metal Butler-type roofs and then coated with five different elastomeric coatings. The coating systems included a catalyzed silicone rubber, a moisture-curing silicone rubber, a hypalon mastic, and two catalyzed butyl-hypalons. Temperatures are recorded on top of the foam, on the metal roof deck, and in the building attics, reveal the insulating quality of the foam. Fuel usage before and after application of the foam is included – a natural gas savings of 53% is indicated after foaming. The performance of each of the five coating systems over a 22-month period is summarized. Best overall performance was observed with the silicone rubbers; the poorest performance was with one of the catalyzed butyl-hypalons. Hail damage was observed on all of the coating systems except the silicones. Minor roof repairs that were done within the first year after installation are reported.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(*When Data Entered*)

CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

INTRODUCTION

Polyurethane foam (PUF) roofing systems have been applied in ever-increasing numbers over the last several years. CEL personnel have inspected a large number of these roofs at Naval Shore Bases and have found that the performances have ranged from very good to very poor. As with most systems involving new materials, these roofing systems sometimes have been misapplied and often have been abused after application. Usually, where such misapplication has resulted in failure of the foam roofing system, the cause of the failure has been unfairly attributed to material problems.

PUF degrades severely when exposed to ultraviolet rays and must, therefore, be protected from direct sunlight as well as from moisture by a good coating system. In addition, because PUF has a relatively high coefficient of thermal expansion and contraction, the protective coating must accommodate such movements without rupture. For this reason, coating systems that are successful on conventional substrates often perform poorly when applied to PUF. Thus, the field investigation described in this report provided a unique opportunity to determine some of the properties necessary for coating systems to adequately protect PUF.

BACKGROUND

The metal roofs of the Butler-type buildings of the Naval Reserve Center (NRC), Clifton, New Jersey, have developed serious leaks due to severe deterioration of the metal as well as opening of many of the lap joints. Since constructon, the roofs had been coated with many different materials including paints, bitumens, and fabric with no lasting results. By 1973 many coats of the above-mentioned materials had accumulated, and the roofs were still leaking. Figures 1 and 2 show portions of the North Building on which repeated attempts to patch leaks had resulted in a buildup of layers of paint and bitumens, most of which had become brittle and were cracking and flaking from the metal. Lighter colored areas are those that were not coated during the most recent application of aluminum-asphalt coating. Dark streaks indicate where attempts were made to patch leaking lap joints with fabric-reinforced bitumen. Figure 3 shows the major portion of the roof of the interconnecting Boiler House as well as a portion of both the North (foreground) and South Buildings. Evidence of leaks were also found where the Boiler House roof joins the South Building. Cracked and flaking coatings are evident in Figure 4, which is a close-up of one of the areas near the roof ridge. At the time of construction of the buildings, the underside of the metal roofs had been sprayed with an asbestos insulation which, upon becoming water-

Figure 1. North Building Showing Accumulation of Old Coatings, Before Reroofing

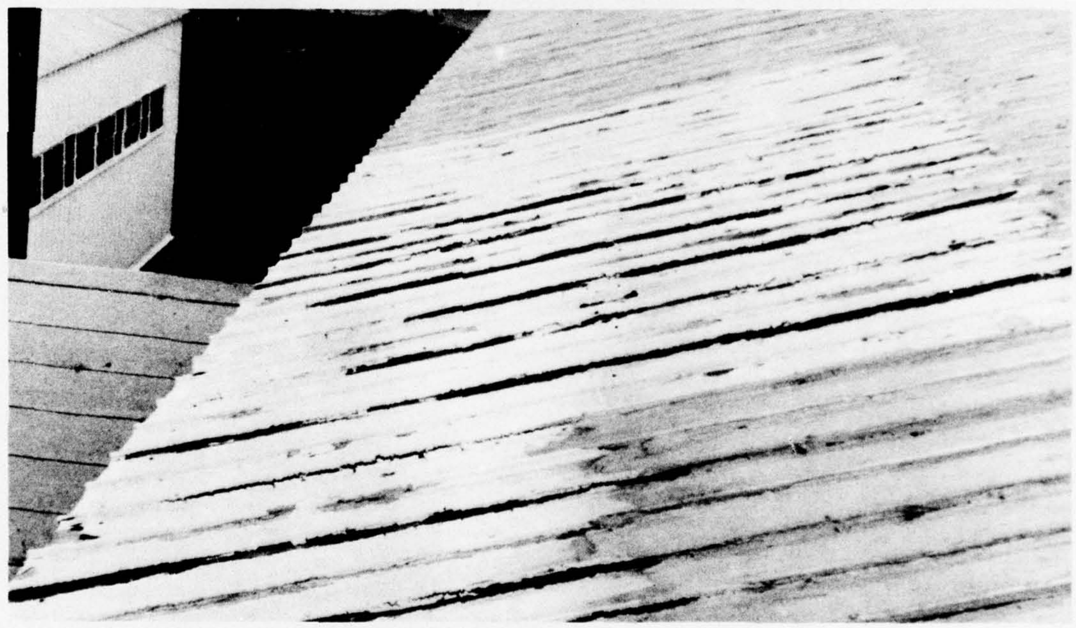


Figure 2. North Building Showing Paint and Bitumen Accumulations, Before Reroofing

soaked, was peeling off in large sheets. Corrective maintenance was planned for FY-74 by the Northern Division of the Naval Facilities Engineering Command (NORDIVNAVFAC). Instead of the more conventional procedure of cleaning and sealing all lap joints, patching holes, applying a protective coating, and installing new insulation, it was proposed that a sprayed-in-place polyurethane foam roofing system be utilized.

It was requested that the Civil Engineering Laboratory (CEL) work jointly with NORDIVNAVFAC in developing an experimental plan for the installation. Appendix A contains the test plan that was approved for implementation. The contract specification was prepared by NORDIVNAVFAC. Appendix B contains the portion of the specification for which CEL made technical recommendations relating to roof surface preparation and designation and application of foam and coatings. National Bureau of Standards (NBS) Technical Note 778* was referred to by CEL personnel in formulating their recommendations.

DESCRIPTION OF TEST LAYOUT

The test buildings consist of two Butler-type metal structures, a "North Building" and a "South Building." They are connected at about midpoint by a small concrete block structure, subsequently called the "Boiler House," which contains the steam boiler and a connecting passageway. The North Building is 162 feet long and 40 feet wide, and the South Building is 203 feet long and 40 feet wide. While both buildings have attics, the attic in the North Building extends only about one-third of its length. The Boiler House has a plywood roof deck over wood trusses and had wide selvage roll roofing.

The total roof area of the buildings was divided into five approximately equal sections, permitting application of five different coating systems over the PUF. This provided an opportunity to determine the relative capability of different generic types of coating systems to protect PUF from the weather. To preclude the introduction of an additional variable, the same PUF product was used on all five sections of the roof. In view of the energy crisis, the plan included measuring the insulation efficiency of the foam with thermocouples placed throughout the roofing system and inside the buildings. It was also planned to monitor consumption of natural gas for heating after installation of the PUF systems. Figure 5 shows a complete layout of the roof coating sections and the location of the thermocouples.

---

* National Bureau of Standards Technical Note 778: Guidelines for Selection of and Use of Foam Polyurethane Roofing Systems, by W. C. Cullen and W. J. Rossiter, Jr., May 1973.

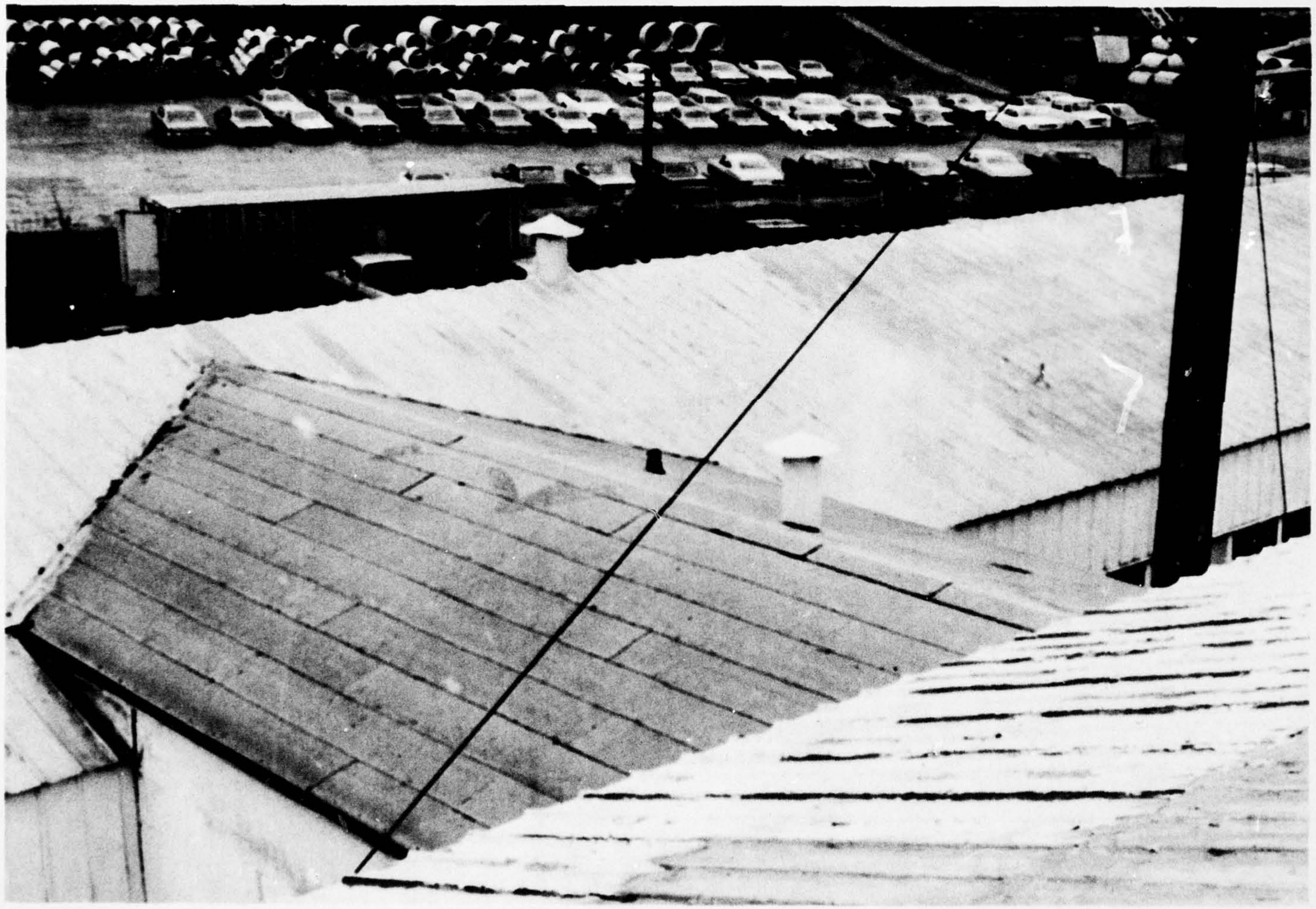


Figure 3. Portions of North Building (Foreground) and South Building and Interconnecting Boiler House, Before Reroofing

Figure 4. Roof Ridge Showing Cracked and Flaked Coatings, Before Reroofing

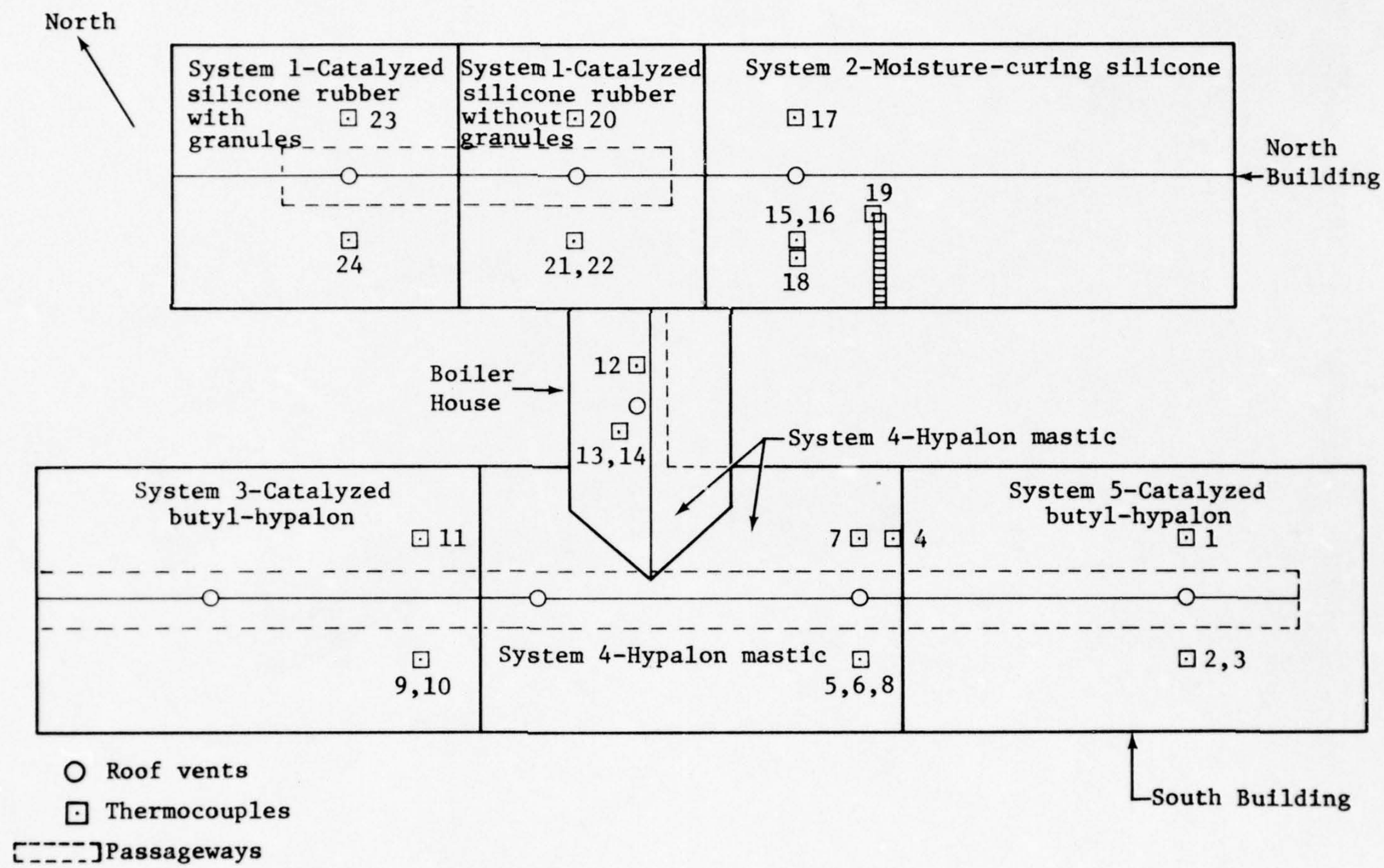


Figure 5. Layout of Thermocouples and Coating Systems on Reserve Center Buildings

The thermocouples were installed:

(1) On the steel deck prior to foaming, i.e., beneath the foam
(2) On top of the foam, i.e., beneath the coating
(3) In the attic spaces
(4) On the antenna masts to measure outside air temperatures

SELECTION OF MATERIALS

The materials selected for study were based primarily on results of a state-of-the-art survey and some laboratory tests. The location of the five coating systems relative to one another was based on their compatibility as determined by information obtained from suppliers and by adhesion tests of one system to another in the laboratory.

Asphalt Primer

A cutback roofing asphalt conforming to Federal Specification SS-A-00701a was selected for the primer. It is to be applied prior to the PUF, but after certain minimum surface preparations. Recommended application rate for the primer is 200 to 400 sq ft/gal.

Polyurethane Foam

The criteria set forth in NBS Technical Report 778 were used as a basis for selecting the PUF to be applied over the asphalt-primed roof. These criteria as well as the manufacturer's values for the selected foam and results from some CEL tests are given in Table 1. A comparison of the values for each criterion shows that the chosen foam did not conform in every case. However, the PUF material selected meets the requirements as closely as most of the other PUF materials and has been widely used throughout the country.

Protective Coatings

The CEL state-of-the art survey indicated that coatings that perform well in protecting PUF from the weather are elastomeric in nature. At the time these selections were made, the coatings for which sufficient performance data were available to enable an intelligent selection were either silicones, butyl-hypalon combinations, or hypalons. Thus, the test coatings selected included two different types of silicones, two different types of butyl-hypalons, and a hypalon. Another important criterion for this selection, as indicated in Table 1, was that the coated foam should have a UL 790 Class A, B, or C rating for fire. The selected coating systems are described in more detail below, with the manufacturers and trade names of the materials listed in Appendix C.

Table 1. Selected Properties for Urethane Foam Used at NRC Clifton

Performance Criteria	NBS Criteria	Manufacturer's Data for Foam Selected	CEL Test Results	Test Method
Fire Safety	UL Class B	UL Class A, B, or C when properly coated	none	UL-790 ASTM E 108-58
Closed cell content (%)	>90	>90	none	ASTM D 2856-70 ASTM D 1940
Water absorption (lb/sq ft)	<0.02	0.10	none	ASTM D 2842-69
Water vapor permeability (perm in.)	<3.0	2.0	none	ASTM C 355-64
Tensile strength, perpendicular to rise (psi)	>25	28	45	ASTM D 1623-64
Shear strength, parallel to rise (psi)	>25	22	none	ASTM C 273-61 (renewed 1970)
Density (lb/cu ft)	>2.0	2.0	2.3	ASTM D 1622-63 (renewed 1970)
Compressive strength, parallel to rise (psi)	>30	25	40	ASTM D 1621-64
Coefficient of linear thermal expansion (in./in./°F)	$<40 \times 10^{-6}$	60×10^{-6}	none	NBS Test Procedure for BUR Membranes
Volume change (%):				ASTM D 2126-66
At -40°F, ambient RH for 1 week	±3		none	
At 140°F, ambient RH for 1 week	+5		none	
At 158°F, 100% RH for 1 week	+12		none	
At 160°F, ambient RH for 4 weeks		+6	none	
At 160°F, 100% RH for 4 weeks		+15	none	
K-value (Btu/sq ft-hr-°F/in.)	none	0.11 to 0.14	none	ASTM C 177-71

System 1. Catalyzed Silicone Rubber. This system consists of one coat of a medium-gray, catalyzed silicone rubber base coat, and one coat of a cement-gray, catalyzed silicone rubber top coat. The recommended application rate for both base and top coats is 1 gal/100 sq ft to provide a nominal wet film thickness of 16 mils and a nominal dry film thickness of 10 mils. Minimum recommended dry film thickness of the total system is 20 mils.

Because of the short pot life of the catalyzed system, application requires a special unit in which the two compounds are mixed in the spray gun just prior to leaving the nozzle. Gray ceramic granules were broadcast at the rate of 50 lb/100 sq ft into the wet top coat on one-half of the area covered with this system. The granules are supposed to provide a longer-wearing and more durable surface. This coating system is referred to as "breathing" or "vapor permeable", because it allows passage of moisture vapor but not liquid water.

System 2. Moisture-Curing Silicone Rubber. This system consists of two coats of a single component moisture-curing silicone rubber. The recommended application rate for the light gray base coat and the white top coat, identical except for color, is 1 gal/100 sq ft to provide a wet film thickness of 10 mils and a dry film thickness of 7.5 mils. Minimum recommended dry film thickness of the total system is 15 mils. This silicone coating system is also referred to as "vapor permeable."

System 3. Catalyzed Butyl-Hypalon. This system consists of a two-component black catalyzed butyl base coat and a two-component white hypalon top coat. The application rate recommended for the base coat of butyl is 2 gal/100 sq ft to provide a minimum wet film thickness of 20 mils and a minimum dry film thickness of 10 mils. Application of the catalyzed butyl base coat requires special equipment for mixing the two components prior to leaving the spray gun. The two-component white hypalon top coat, which can be applied with conventional airless spray application, is batch-mixed (catalyst mixed with resin) prior to spray application; the recommended application rate is 1.5 gal/100 sq ft to provide a minimum wet film thickness of 8 to 9 mils and a minimum dry film thickness of 5 mils. Minimum recommended dry film thickness of the total system is 15 mils. This butyl-hypalon coating system is "nonbreathing" or "vapor impermeable," because it inhibits passage of both water vapor and liquid water.

System 4. Hypalon Mastic. This one-coat system consists of a single component white hypalon mastic; the recommended application rate is 6 gal/100 sq ft to provide a minimum wet film thickness of 90 mils and a minimum dry film thickness of 30 mils. This hypalon coating system is classed as "vapor impermeable."

System 5. Catalyzed Butyl-Hypalon. This system consists of a two-component cationically polymerized tan butyl base coat and a one-

component white hypalon top coat. The recommended application rate of the butyl base coat is 2.5 gal/100 sq ft to provide a minimum wet film thickness of 39 mils and a minimum dry film thickness of 18-1/2 mils. The two components of the butyl base coat are batch-mixed prior to spraying. The application rate recommended for the white hypalon top coat is 1 gal/100 sq ft to provide a wet film thickness of 12 mils and a dry film thickness of 4 mils. Minimum dry film thickness recommended for the total system is 22-1/2 mils. This butyl-hypalon system is also classed as "vapor impermeable."

EXPERIMENTAL PROCEDURES

Thermocouple Installation

Thermocouples of copper constantan wire were installed at various locations to study temperature distribution in the roof systems and inside the buildings and to determine the time-dependent insulation efficiency of the PUF. The thermocouple stations and their locations are shown in Figure 5 and listed in Table 2. Locations called "North" are actually north-easterly and those called "South" are south-westerly due to the orientation of the buildings. On the Boiler House, "West" is actually north-westerly.

The thermocouples placed at the "base of the foam" were attached to the steel roof deck on top of the asphalt primer and covered with PUF. Thermocouples were also attached to the "top of the foam" just prior to application of the coating.

On the North and South Buildings, thermocouples were placed on both sides (North and South) of the roof ridge to determine effects of location with respect to intensity of the sun or prevailing winds. Since maintenance of desired downstairs temperatures is usually a function of the heat transfer into or out of the attic, some of the thermocouples were placed in the attics to determine how effectively the PUF insulation could stabilize these temperatures year-round. Outside air temperatures reported herein were measured by a thermocouple mounted on a catwalk on the roof of the North Building. The thermocouple wires, which were attached to the roof deck with an epoxy putty, were brought into the attics from the roof positions through roof vents. (Installation of some of the wires prior to foaming (base of foam) is shown in Figure 6.) The measurements of temperatures from the thermocouples were made on a potentiometer located in a room at attic level in the North Building. Reserve Center personnel have made readings and recorded temperatures at about 0900 and 1400 daily since roof construction was completed in October 1973.

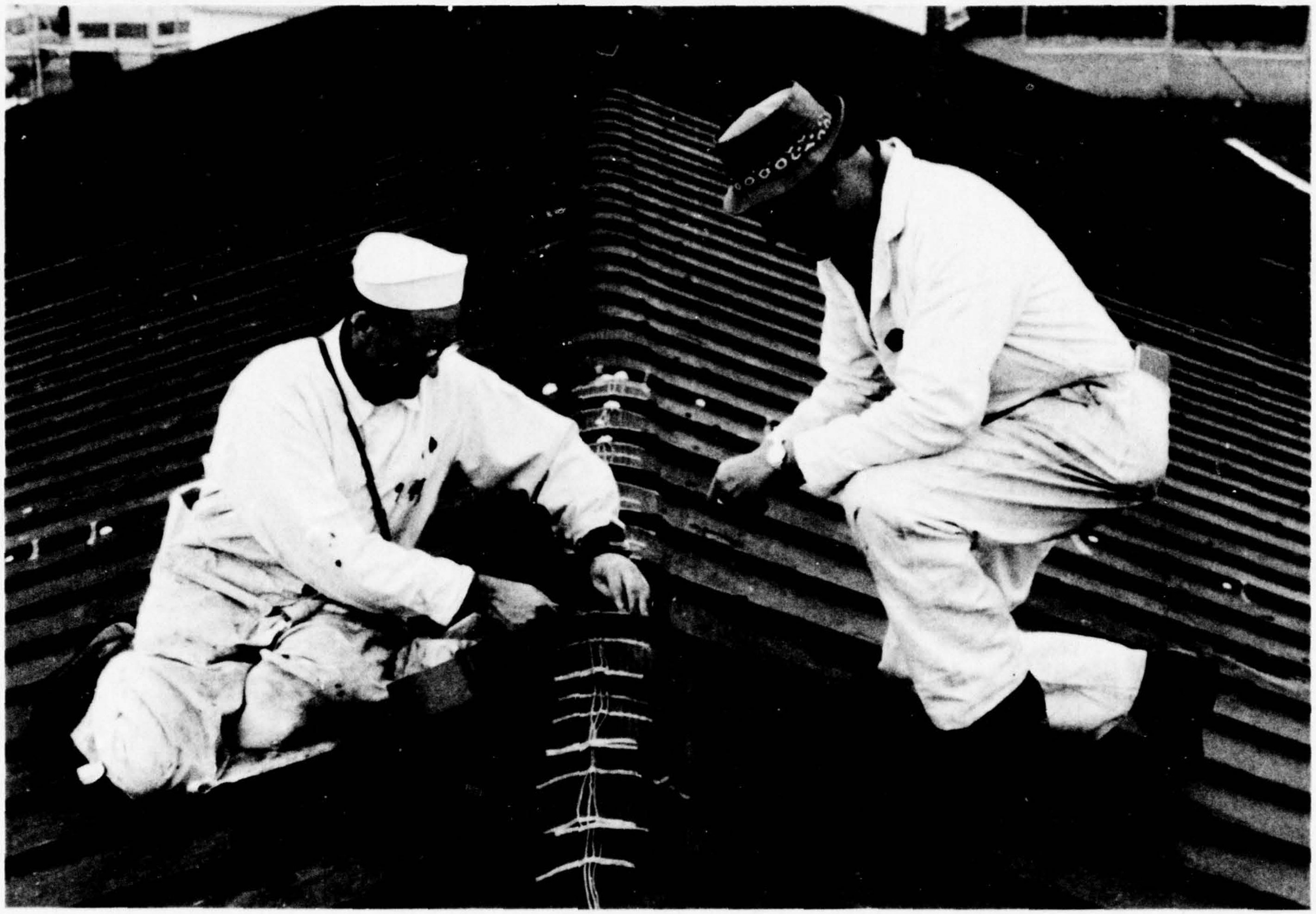


Figure 6. Installation of Thermocouple Wires

Table 2. Location of Thermocouples (Stations)

Thermocouple or Station Number	Coating System	Side of Roof Ridge	Location
1	5	North	At base of foam, South Building
2	5	South	At base of foam, South Building
3	5	South	On top of foam, South Building
4	4	North	In attic of South Building
5	4	South	At base of foam, South Building
6	4	South	On top of foam, South Building
7	4	North	At base of foam, South Building
8	4	South	In attic of South Building
9	3	South	At base of foam, South Building
10	3	South	On top of foam, South Building
11	3	North	At base of foam, South Building
12	4	West	In attic of Boiler House
13	4	West	At base of foam, Boiler House
14	4	West	On top of foam, Boiler House
15	2	South	On top of foam, North Building
16	2	South	At base of foam, North Building
17	2	North	At base of foam, North Building
18	2	South	In attic of North Building
19	2	South	Outside air, on walkway, North Building
20	1	North	At base of foam, North Building
21	1	South	On top of foam, North Building
22	1	South	At base of foam, North Building
23	1 (with granules)	North	At base of foam, North Building
24	1 (with granules)	South	On top of foam, North Building

Roof Renovation

The contract specification required complete removal of all protective coatings, fiberglass cloth, plastic roof cements, and other bituminous materials by sandblasting. The contractor attempted to remove the old materials by sandblasting but stated later that it was extremely difficult if not impossible. The contractor decided to leave much of the old material in place and therefore, proceeded to apply the asphalt primer at a much heavier rate, 50 to 100 sq ft/gal, rather than at the specified rate of 200 to 400 sq ft/gal. CEL personnel later observed that the remaining old coatings were lifting from the steel deck in many places, probably due to the strong solvent in the asphalt primer (Figure 7). In these areas, the old coatings were easily removed with a putty knife, leaving the uncoated galvanized deck exposed. It was decided to proceed with the roofing, after scraping off all of the loosened coatings and spot-priming the areas with asphalt where the base metal roof deck was exposed. Several of the scraped and spot-primed areas can be seen in Figure 8; when the picture was taken, the majority of the spots had already been spot-primed with SS-A-701a.

Spray-Application of Polyurethane Foam

Prior to and during each foam application, windspeed, air temperature, roof surface temperature, and relative humidity were measured and recorded to assure compliance with the contract specification. These observations are presented in Table 3, together with nominal foam thicknesses and coverage. Foam was usually applied to each of the areas in two successive "lifts," with each lift about 3/4 inch thick. One-half of a given "coating area" was foamed first - usually the south slope of the area. Two lifts were usually sufficient to attain the required thickness. As shown in Table 3, roof surface temperature for System 2 was so low that the first lift did not rise properly, necessitating a third lift in half of this section. In some of the sections a partial third lift was applied in isolated areas where foam thickness was below the minimum of 1-1/2 inches. With one exception, to be mentioned later, only that amount of foam was applied on any given day that could be coated with the base coat that same day. To minimize pinholing in the coating, the foam was allowed to "off-gas" for 2 to 3 hours prior to application of the coating.

The PUF was easily sprayed with only an occasional stop due to spray-gun blockage or, in one instance, to improper proportioning of the two components. A typical foaming operation is shown in Figure 9. Notice the use of the cardboard screen to inhibit foam overspray from reaching and depositing onto sides of the building. Measurements of foam thickness were made for each section before moving to the next section (Figure 10). Nominal foam thickness was 1-3/4 to 2-1/4 inches. When foam thickness was found to be below 1-1/2 inches in isolated areas, the foam applicators were directed to spot-spray these areas to bring them up to proper thickness. In a few instances, this resulted in a small area of some sections being as thick as 3 inches. A close-up of a typical foam surface

is shown in Figure 10. Note in Figure 11 footprint indentations in the foam surface made by foam applicators wearing basketball-type shoes.

Spray-Application of Protective Coatings

The five elastomeric protective coating systems were applied as closely as possible in accordance with manufacturers' directions. In determining if proper coverage was being obtained for the protective coatings, the contractor selected a unit area within the test section, such as 100 to 200 square feet, and applied what was considered a sufficient thickness of the material to obtain this coverage. If the material usage was either high or low, the coating applicator adjusted the amount of coating applied accordingly. In addition to this technique, the CEL representatives monitoring the application occasionally placed metal plates in the path of the spray gun, and these were coated in the same manner as the foam surface. Immediately after coating, the metal panels were removed, and the wet film thickness determined with a Nordson-type wet film thickness gage. After the coating on the metal panels had dried, the dry film thickness was determined with an Elcometer magnetic dry film thickness gage. If the wet film measurements indicated improper coverage, the spray operator was directed to adjust the application accordingly. This sometimes resulted in a small area of a given test section being either too thin or too thick, while the thickness in the remainder of the section was satisfactory. Instances such as these are described below under the individual coating systems. Nominal wet and dry film thicknesses in addition to other descriptive information on the five coating systems are presented in Table 4.

System 1. Catalyzed Silicone Rubber. This system consists of two coats of catalyzed silicone rubber of contrasting colors to facilitate complete coverage of each of the coats. The medium gray base coat was permitted to cure a minimum of 2 hours before the cement gray top coat was applied; both base and top coats were applied the same day. As noted previously, these coatings require special spray equipment for their application because of a very short pot-life for the mixed components. The two components are mixed in the proper ratios just before leaving the spray gun. To obtain a good cure, proper metering of the two components by the spray apparatus is critical, and the operators have to calibrate the equipment prior to applying each of the two coats of the system.

No problems were encountered either with the silicone coating or with the granules, although the applied coating was about 50% thicker (total of 30 mils) than recommended by the manufacturer (20 mils). Within 5 minutes after applying the top coat, granules were wafted into the still-wet top coat on the western half of the System 1 area to assure proper bonding of the granules to the top coat. A representative of the manufacturer of the catalyzed silicone rubber coating was present during both the foaming and coating applications. The completed south side of this section is presented in Figure 12, in which the darker colored area on the left has the granules.

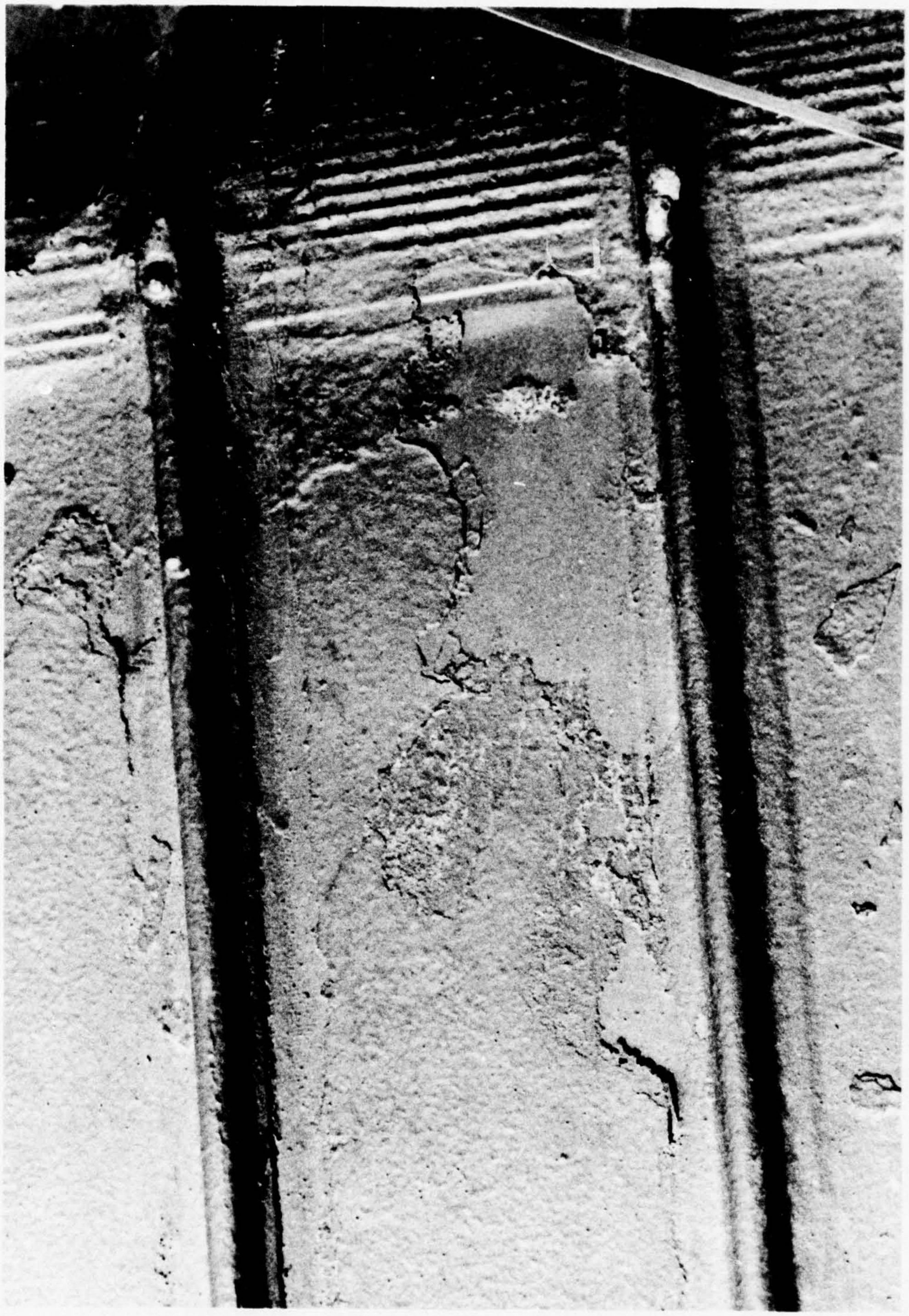


Figure 7. Loose Coating Caused By Asphalt Primer Solvent

Figure 8. Spot-Primed Areas Ready For Foam Application

Figure 9. Spray-Application of Polyurethane Foam

Figure 10. Measurement of Foam Thickness

Figure 11. Close-up of Typical Foam Surface

Figure 12. Completed South Side of Catalyzed Silicone Rubber Coating Section (System 1)

Table 3. Application Data for Foam

System Number and Description	Roof Surface Temperature (°F)	Air Temperature (°F)	Relative Humidity (%)	Wind Speed (mph)	Number of Lifts	Nominal Foam Thickness (*inches*)	Quantity Applied	
							Pounds	Square Feet per Pound
1. Catalyzed silicone rubber	68-95	50-56	40-62	2.6-4.3	2	1-3/4	1,300	2.7
2. Moisture-curing silicone rubber	50-62	57-60	58-75	2.2-5.4	2 to 3	1-3/4	1,400	2.5
3. Catalyzed butyl-hypalon	95-114	64-73	38-67	2.4-3.6	2	2-1/4	1,600	1.9
4. Hypalon mastic	85-108	58-64	34-50	2.0-4.5	2	2	1,800	1.9
5. Catalyzed butyl-hypalon	87-115	62-70	30-50	1.5	2	2	1,600	1.9

Table 4. Application Data for Elastomeric Coating

System Number and Description	Number of Coats	Nominal Film Thickness (mils)			Number of Squares Coated	Application Rate		
						Total Gallons Used	Coverage (gal/sq ft)	
		Wet	Dry	Total			Actual	Mfgr. Rec.
1. Catalyzed silicone rubber								
Medium gray base coat	1	25	12.5		35.5[b]	40	1.1	1.0
Cement gray top coat	1	35[a]	17.5	30		60	1.7	1.0
2. Moisture-curing silicone rubber								
Light gray base coat	1	13[a]	6.5		35.5	40	1.1	1.0
White top coat	1	22	10.5	17		40	1.1	1.0
3. Catalyzed butyl-hypalon								
Black butyl base coat	1 to 2[c]	24	7.5		30	70	2.3	2.0
White hypalon top coat	1	14	3.5	11		50	1.7	1.5
4. Hypalon mastic								
White hypalon mastic	1 to 2[c]	95	32	32	34.7	220	6.3	6.0
5. Catalyzed butyl-hypalon								
Tan butyl base coat	1	50	22			80	2.6	2.5
White hypalon top coat	1	16	4	26	30.9	35	1.1	1.0

a) Film thickness estimated.

b) 900 pounds of mineral granules were sprinkled in the wet top coat of one-half of the test area at a rate of 51 lb/sq ft.

c) A second light coat was applied in some areas where coating thickness was below minimum.

System 2. Moisture-Curing Silicone Rubber. The worst weather encountered during the entire roof construction period happened on the day this section was begun. The sky was completely overcast, and roof surface temperatures were low, as indicated in Table 3. Because the roof deck temperature was only 50°F when foaming started, the first lift of foam did not rise much. As a result, it was necessary to apply three lifts of foam to part of the roof area in this section. The first lift of foam did insulate the cold roof deck surface from the second lift, thereby permitting the second lift to rise in a normal manner.

This one-part, moisture-curing silicone rubber coating was easily applied with conventional airless spray equipment. The light-gray base coat was permitted to dry overnight, and the white top coat was applied the following day. The completed south side of System 2 is pictured in the background of Figure 13.

System 3. Catalyzed Butyl-Hypalon. A minor problem arose during foaming of the north side of this section when the proportioning units of the foam spray apparatus malfunctioned. Until this occurred, the foam was of good quality. Fortunately, the operators noticed the problem almost immediately, stopped foaming, and rectified the problem. Although it was believed that all poor quality foam resulting from the malfunction had been removed and the area refoamed at the time, a few minor problems arose during the first year which required correction by the contractor at a later date. These are discussed later in this report.

The coating materials of System 3 consist of one coat of a black, catalyzed butyl rubber base coat and one coat of a white, catalyzed hypalon top coat. The catalyzed butyl base coat has a relatively short pot-life and requires a special spray gun and apparatus for application. The two components of the butyl are thoroughly mixed as they pass through the mixing tube of the spray gun. Figure 14 shows the special spray gun being used to apply the black butyl base coat.

A great deal of trouble was encountered during application of the base coat. The spray gun became plugged a number of times, and each time it was necessary to disassemble and clean it thoroughly. In addition, the black butyl base coat was so thin that it tended to run when applied at the recommended rate. This was a greater problem on the north side than on the south side of this section. Accordingly, the north side was given a second coat of butyl the following day.

The white hypalon top coat was applied between 4 hours and 20 hours after application of the base coat. The hypalon was also very thin and had very poor hiding characteristics when applied at the recommended rate. Therefore, this system had a very blotchy appearance when completed. Both the base and top coats of System 3 were applied under the direction of the manufacturer's representative. The north side of the completed System 3 section is pictured in Figure 15. The light-colored spots are places where the manufacturer's representative attempted to overcome the splotchiness by spot-touching with the hypalon top coat the day following completion of the system.

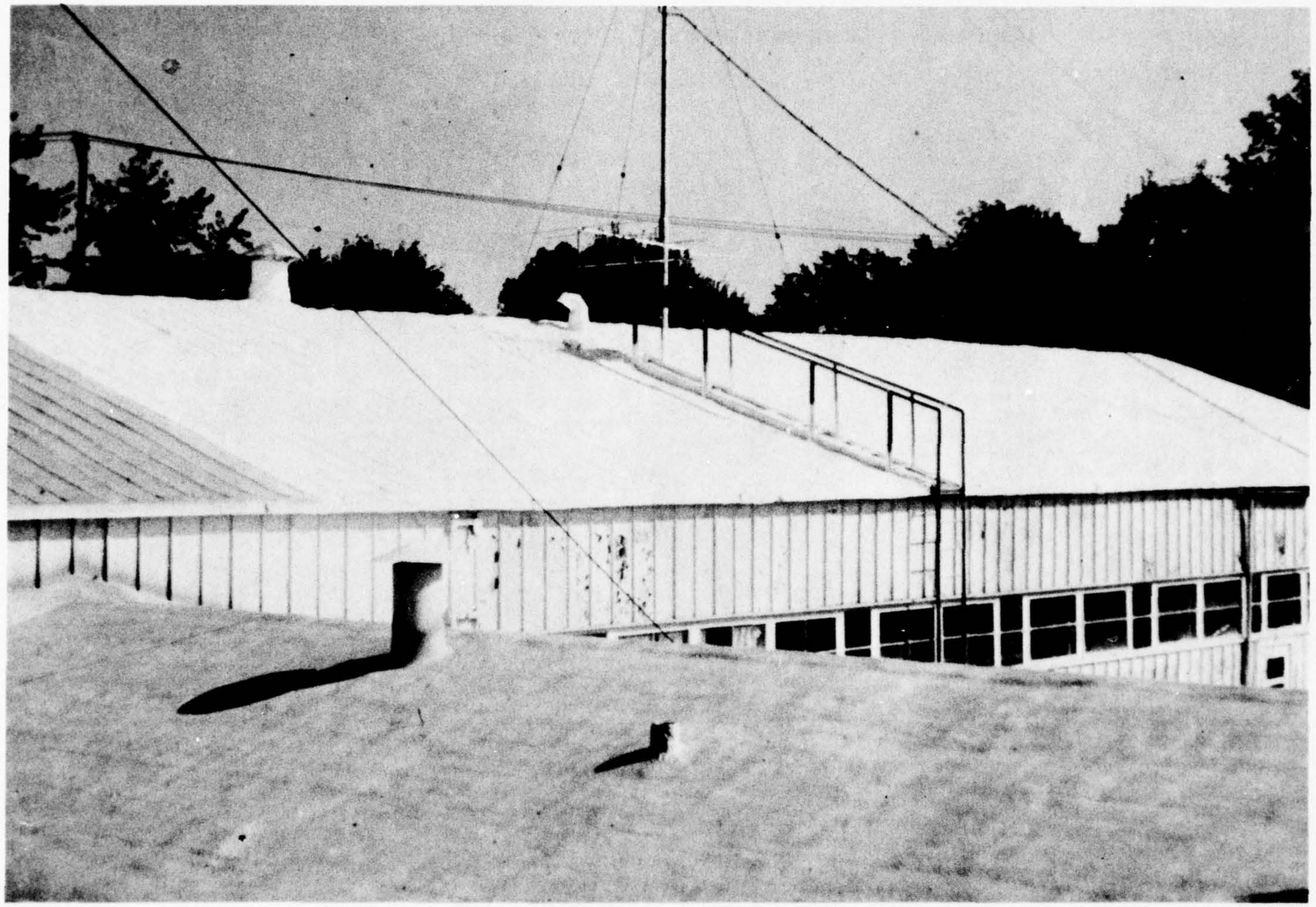


Figure 13. Completed South Side of Moisture-Curing Silicone Rubber Coating Section (System 2)

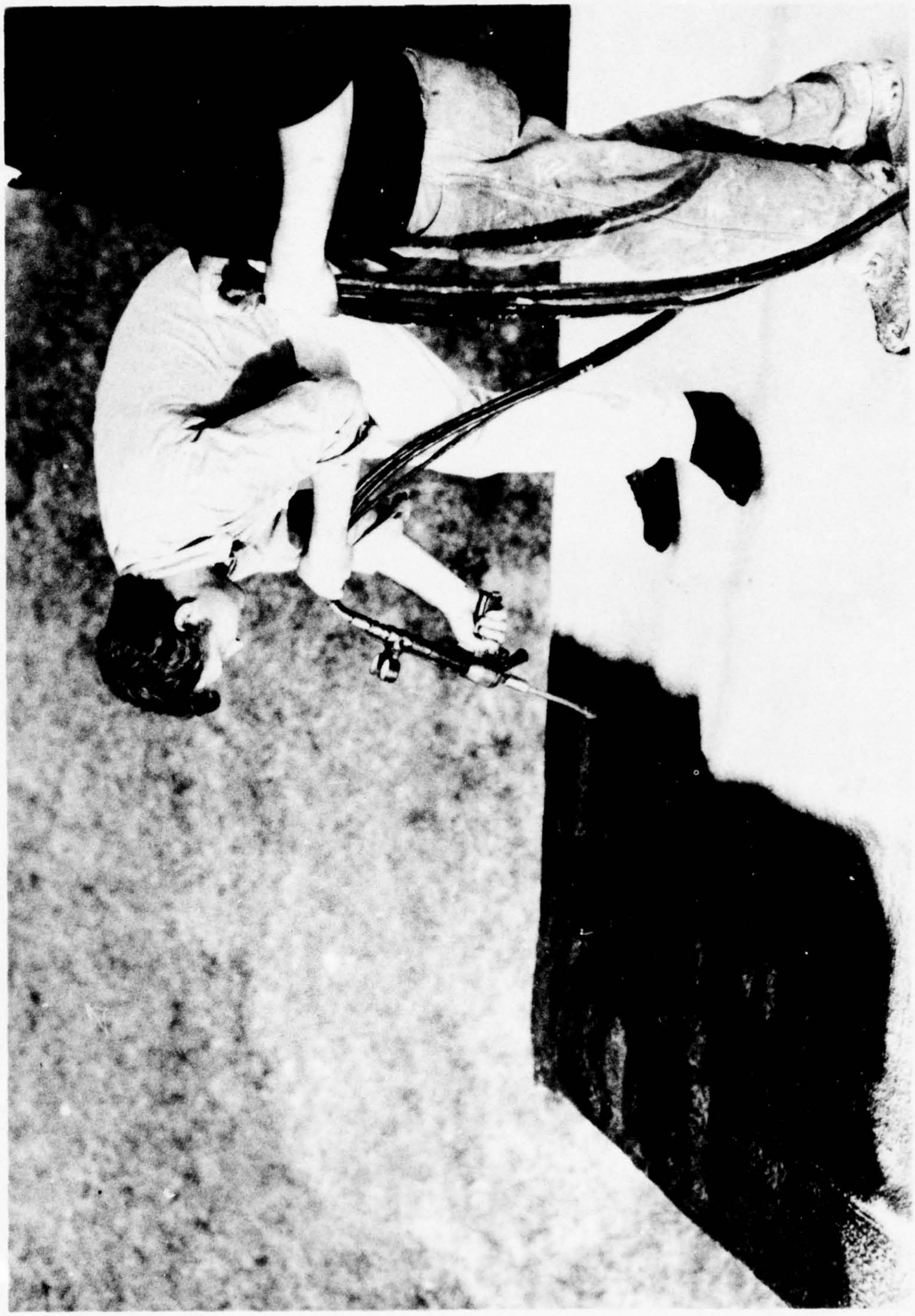


Figure 14. Spraying Black Butyl Base Coat of Catalyzed Butyl-Hypalon Coating (System 3) With Special Spray Gun

Figure 15. Completed North Side of Catalyzed Butyl-Hypalon Coating Section (System 3)

System 4. Hypalon Mastic. This coating system consists of one coat of a white, single-component hypalon mastic applied with conventional 40:1 ratio airless spray equipment. Although only about 30% solids, the mastic was very thixotropic, making spraying somewhat difficult. Heating the mastic with an in-line heater at about 125°F reduced the viscosity of the material sufficiently to enable it to be sprayed, but it was still necessary to purge the spray gun frequently to remove blockage and maintain a proper spray pattern. Figure 16 shows the hypalon mastic being applied to the foamed roof on the Boiler House.

All of the System 4 section was foamed on the same day. The contractor intended to coat all the foam on that same day, but the difficulties encountered with the spraying of the hypalon mastic prevented doing this. Therefore, the foam on the south slope of the section on the South Building was not coated until the following day. The foam was exposed to the weather for about 22 hours before it was coated. Considerable dew had accumulated on the foam, and it had to be allowed to dry thoroughly the next day before applying the coating. To facilitate drying, the foam surface was swept to remove as much water as possible. Coating application to the dried foam was started shortly after noon.

Coating thickness was probably more inconsistent on this system than on any of the others. The high single-coat wet film thickness necessary to obtain a dry film thickness of 30 mils made it difficult for the operator to judge coverage. The coating was first applied too thin and then too thick before proper adjustments were made. In a few areas where the coating was too thin, primarily on the Boiler House, a second coat was applied the following day. In areas where it was applied too thick (late in the afternoon of the first day), it was tack-free the next morning but far from being completely dry. It was noted that when these thicker areas were touched, the film appeared spongy, and water tended to run from the spot that was touched, indicating absorption of dew overnight.

System 5. Catalyzed Butyl-Hypalon. This system consists of one coat of a tan, catalyzed butyl rubber base coat and one coat of a single-component, white hypalon top coat. The catalyst and resin of the base coat are mixed before spraying, and both coatings are easily applied using conventional airless spray equipment.

As recommended by the manufacturer, the top coat was not applied until the base coat had cured for 2 days. This was to allow for proper solvent evaporation from the base coat to minimize pinholing in the top coat. The completed system is shown in Figure 17.

Figure 16. Spraying Hypalon Mastic Coating (System 4)

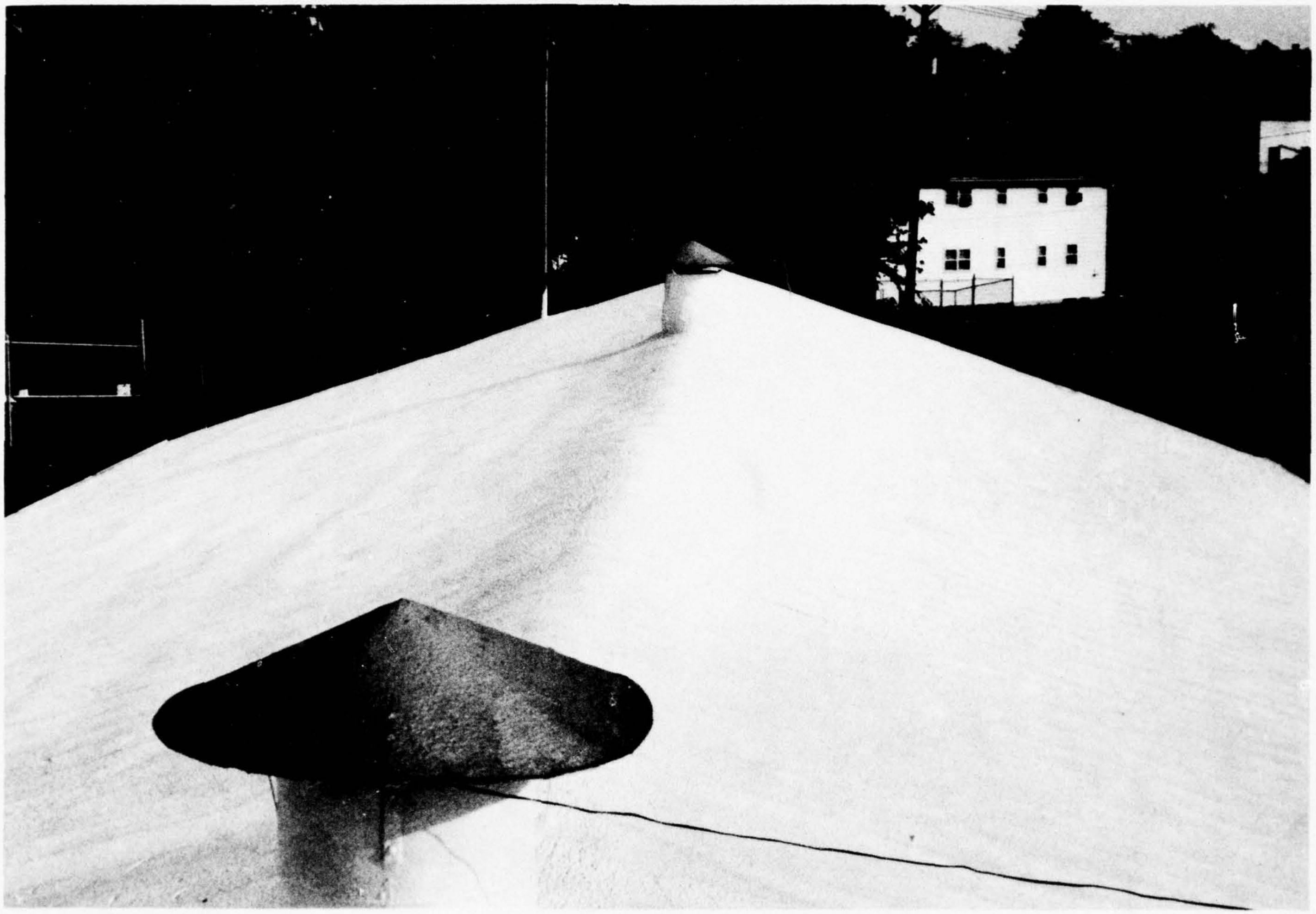


Figure 17. Completed Section of Catalyzed Butyl-Hypalon Coating (System 5)

ROOF AND BUILDING TEMPERATURES

As mentioned earlier, the roofing systems were rather extensively thermocoupled. Thermocouples were placed beneath the foam and on top of the foam in each of the five coating sections, as well as in the attic of each building. Outside air temperature was also determined above the North Building. Temperature readings were made manually with a direct-reading potentiometer. Reserve Center personnel usually recorded the readings twice daily at about 0900 and 1400, although occasionally only one set of readings was made on a given day. The temperature data reported herein covers the time frame from December 1973 to November 1974. It is expected that as more temperature data are collected, they will reveal any changes in the insulation efficiency of the foam as well as any previously undisclosed characteristics of spray-applied PUF-elastomeric coating systems.

The temperature data are presented in three forms: (1) average daytime temperatures, (2) daytime temperature differences, and (3) overnight temperature differences. Average daytime temperature is merely the average of the morning (0900) and the afternoon (1400) temperatures; daytime temperature difference is obtained by subtracting the morning temperature from the afternoon temperature; overnight temperature difference is obtained by subtracting the afternoon temperature from the temperature measured the following morning.

Average daytime temperatures are presented in Figure 18 for Systems 1, 2, and 5. Some significant characteristics are revealed, most notably the small day-to-day temperature variations at the base of the foam compared to the top of the foam or to the outside air temperatures. For the silicone systems, Figures 18a and 18b, the base of the foam temperatures generally fall within the range of $70° \pm 10°F$, although in the summer months the variations are somewhat larger due to hotter outside temperatures. This relatively narrow range of temperature variations is due, of course, to the excellent insulating characteristic of the foam.

As expected, the top-of-foam temperatures are cooler during the winter months and warmer during the summer months, and their day-to-day variations are considerably greater than those at the base of the foam. The nonwhite coatings are good solar heat absorbers and good heat-sinks; during hot summer days the top-of-foam temperatures can rise above 150°F. System 1 is gray, while System 2, although originally white, has become gray due to retention of dirt.

Figure 18a also shows the ambient outside air temperatures. A comparison of outside air and top-of-foam temperatures shows very little difference between the two from December through February (winter months). The roof does not receive a large amount of radiation from the sun during winter due to rather frequent cloud cover and shielding of the roof surface by snow. As the weather warms, however, the roof receives more sunlight and, hence, attains higher temperatures as well as exhibiting greater day-to-day temperature variations. The coated foams are better

heat-sinks than the ambient air thermocouple and therefore, are not affected as much by breezes (chill factor). This makes the day-to-day temperature variations of the outside air lower than those at the top of the foam.

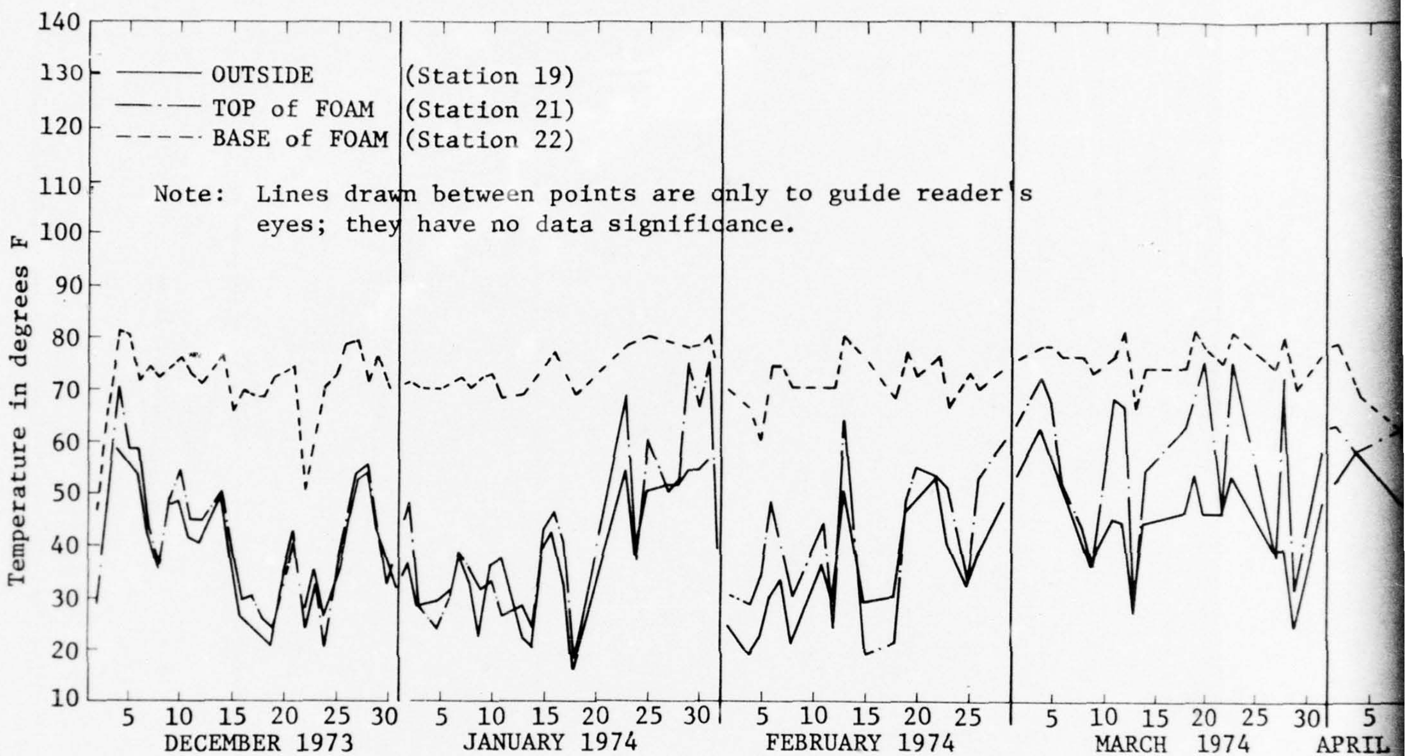
In addition to base- and top-of-foam temperatures, Figure 18b also gives the attic temperatures for System 2. A study of these curves shows, as expected, that the attic and base-of-foam temperatures are very similar throughout the year. While the base-of-foam temperatures in Figure 18a and Figure 18b are generally 70°±10°F, the corresponding temperatures for System 5 (Figure 18c) are closer to 60°±10°F. The base-of-foam temperatures for System 5 are lower most likely because the hypalon top coat is white rather than gray. The white surface reflects more solar radiation and lowers the temperatures at the top of the foam as well as at the base of the foam. To illustrate this, the August 6, 1974 top-of-foam temperatures for System 1 (Figure 18a) and System 2 (Figure 18b) were 155°F and 156°F, respectively; the corresponding temperature of System 5 (Figure 18c) was 135°F, about 20°F cooler.

Figure 19 shows daytime temperature differences for hypalon mastic (System 4) and catalyzed butyl-hypalon (System 3). The overnight temperature differences for hypalon mastic (System 4) and for moisture-curing silicone (System 2) are presented in Figure 20. The primary point of interest with these curves is again their illustration of the excellent insulating efficiency of the foam. Base-of-foam temperature differences on a day-to-day basis are generally on the order of ±10°F, while the top-of-foam temperature differences show wide variations. In addition, daytime temperature differences for top of foam are usually positive, while similar overnight differences are more often negative. Since early morning temperatures are usually lower than afternoon temperatures, this is to be expected because of the manner in which the differences are calculated.

Closer examination of these temperature difference curves reveals that for both daytime and overnight top-of-foam differences, there is more variation for the darker than for the lighter top coats. This is emphasized in Figure 21, which compares top-of-foam daytime temperature differences for a gray coating (System 1) and a white coating (System 4). In many cases, the white coating shows as much as 20° to 30°F less variation than the darker-colored coating. This is presumably due to the fact that the white coatings absorb less solar radiation than the darker coating and, as a result, exhibit a lower heat buildup and temperature variation. In a few instances, the darker coatings exhibited lower temperature differences. It is assumed that this anomaly was due to cloud cover, which reduced the temperature buildup in the darker coatings. The darker coatings are also better heat radiators, which tend to reduce their temperature variations even further.

ROOF PERFORMANCE

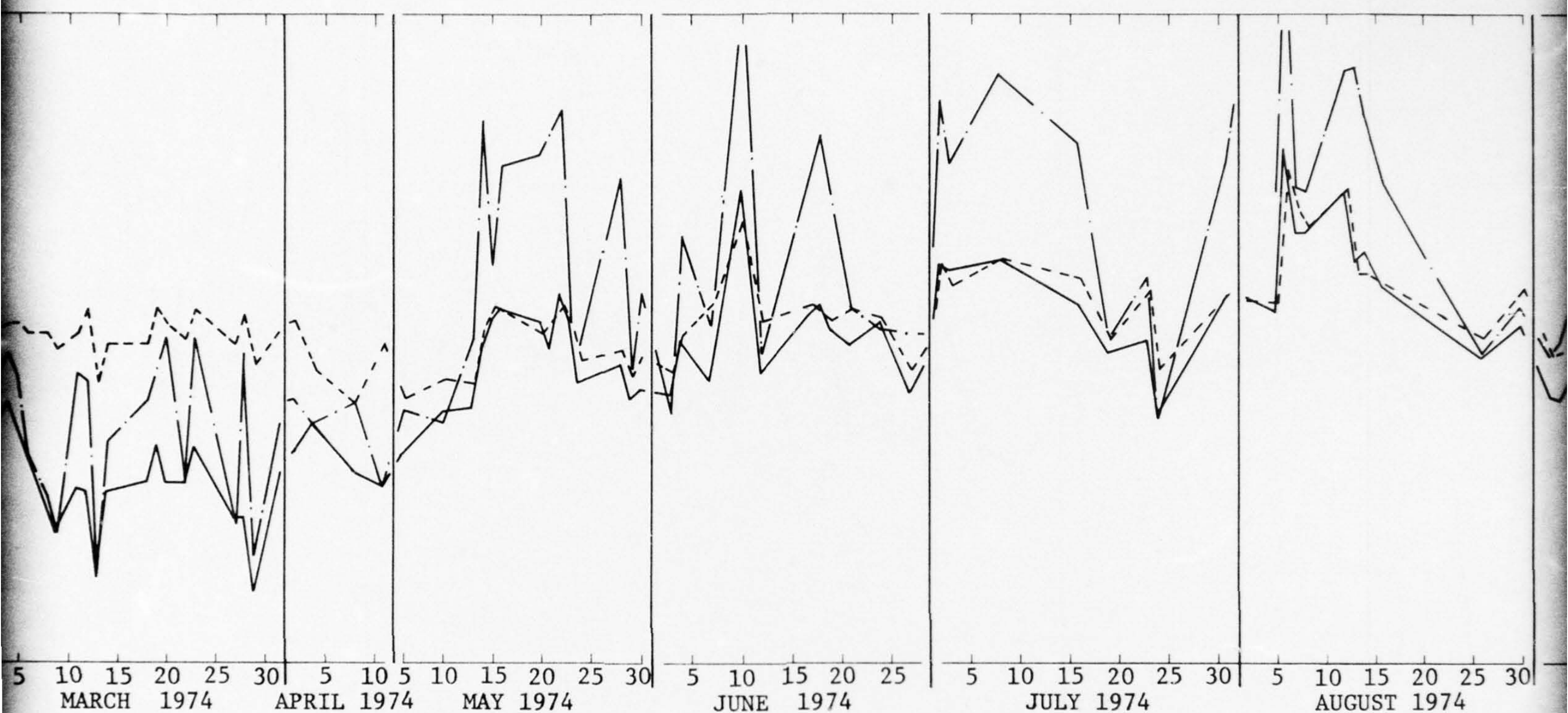
The performance of the five different coated urethane foam roofing systems was determined during on-site inspections by CEL and



140
130
120
110
100
90
80
70
60
50
40
30
20
10
Temperature in degrees F
OUTSIDE (Station 19)
TOP of FOAM (Station 21)
BASE of FOAM (Station 22)
Note: Lines drawn between points are only to guide reader's eyes; they have no data significance.
5 10 15 20 25 30
DECEMBER 1973
5 10 15 20 25 30
JANUARY 1974
5 10 15 20 25
FEBRUARY 1974
5 10 15 20 25 30
MARCH 1974
5
APRIL

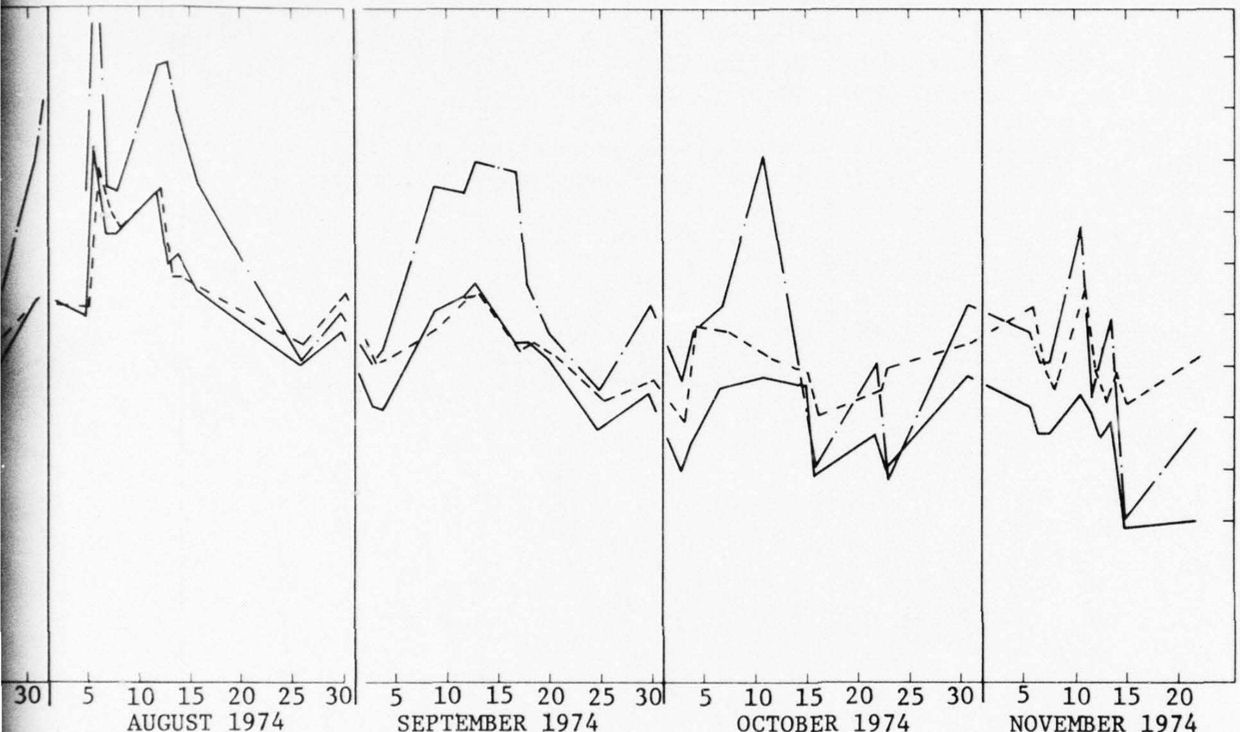
(a)

2

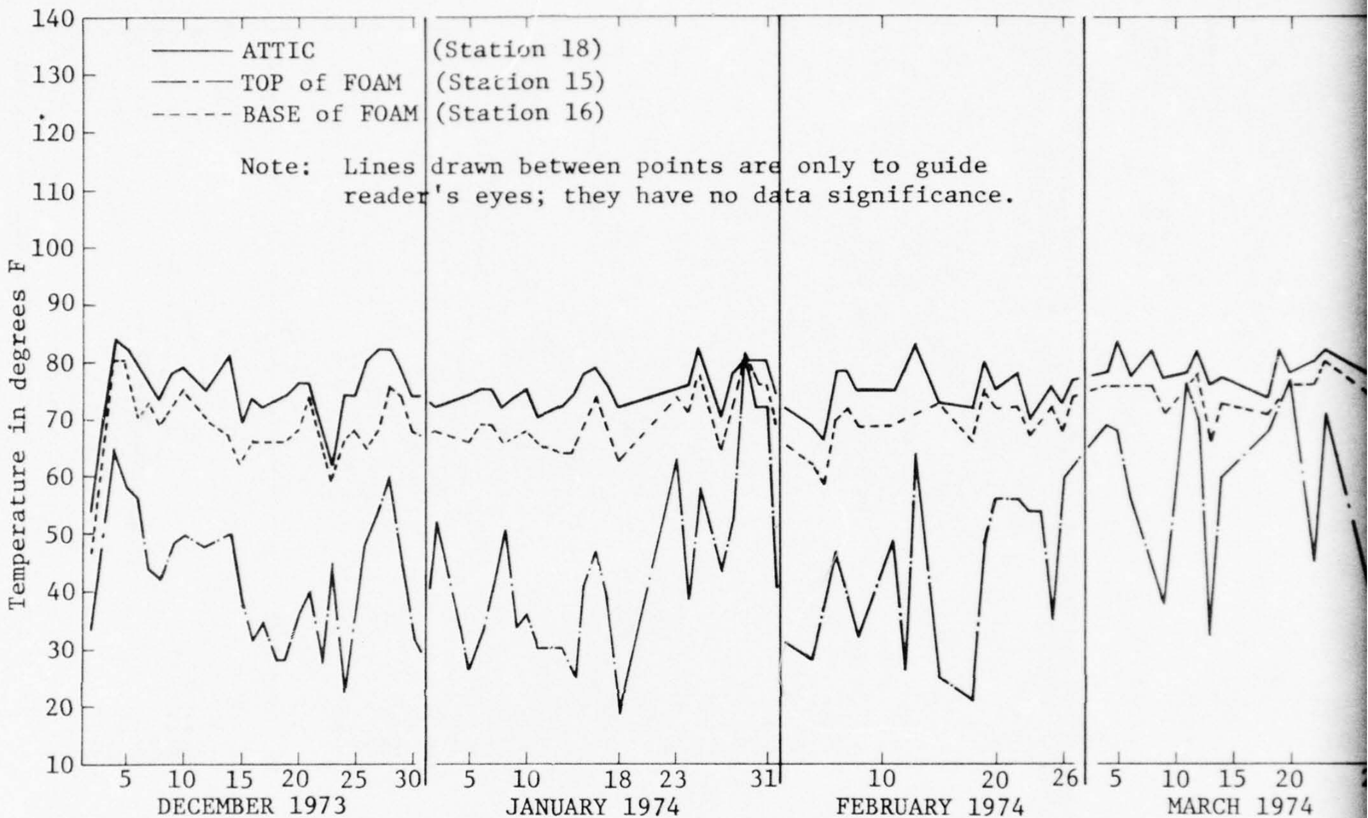


(a) Catalyzed Silicone Coating (System 1) Without Granules

Figure 18. Average Daytime Temperatures

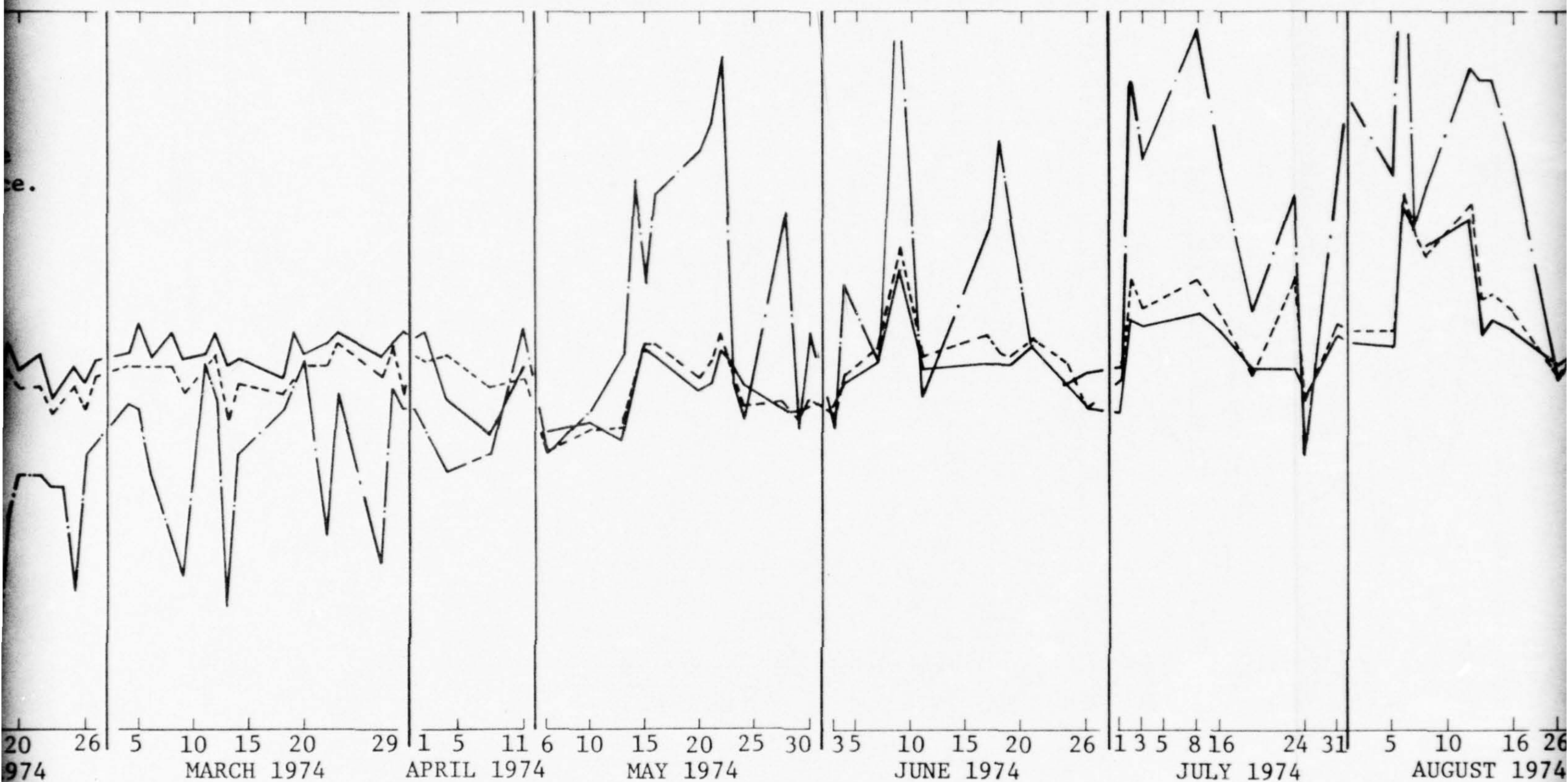

30
5 10 15 20 25 30
AUGUST 1974
5 10 15 20 25 30
SEPTEMBER 1974
5 10 15 20 25 30
OCTOBER 1974
5 10 15 20
NOVEMBER 1974

3


ATTIC (Station 18)
TOP of FOAM (Station 15)
BASE of FOAM (Station 16)
Note: Lines drawn between points are only to guide reader's eyes; they have no data significance.
Temperature in degrees F
140
130
120
110
100
90
80
70
60
50
40
30
20
10
5 10 15 20 25 30
DECEMBER 1973
5 10 18 23 31
JANUARY 1974
10 20 26
FEBRUARY 1974
5 10 15 20
MARCH 1974

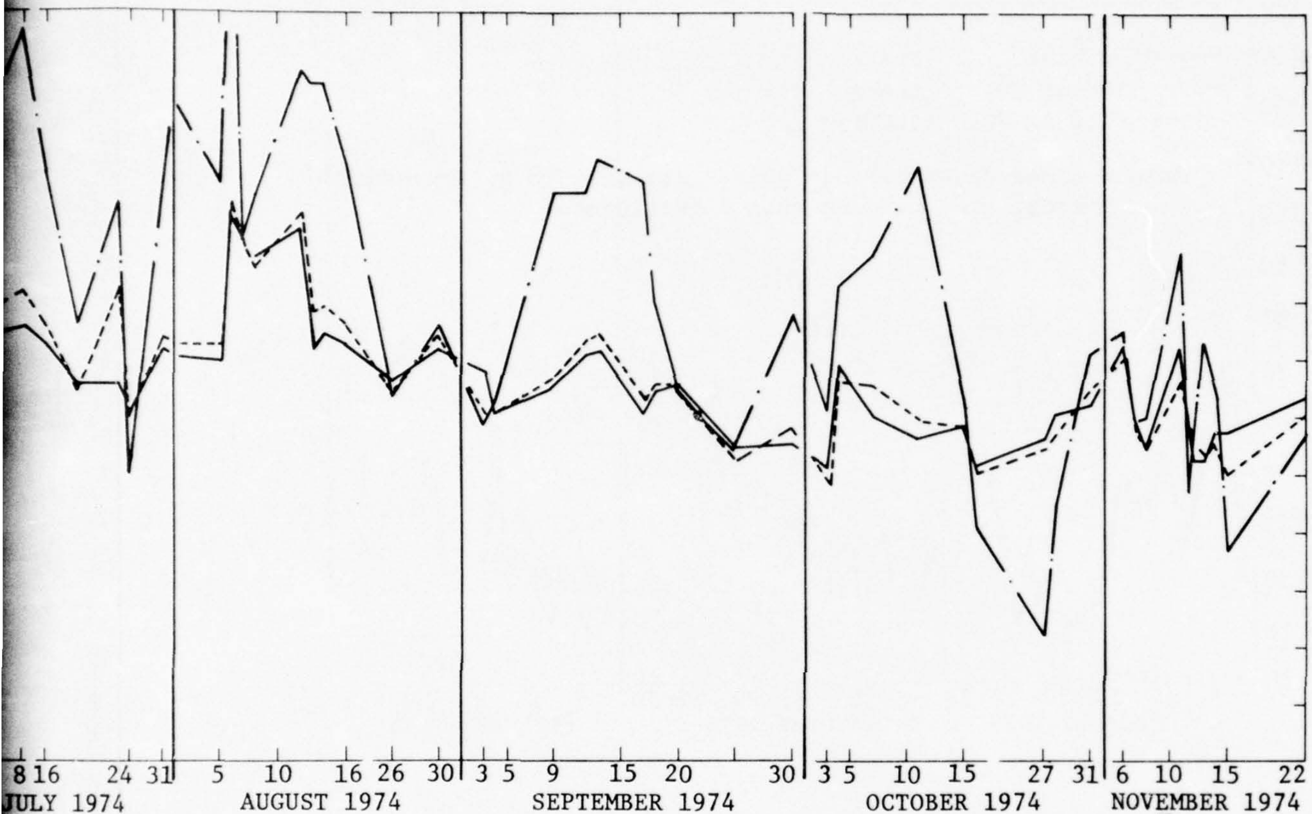
(b) Mois

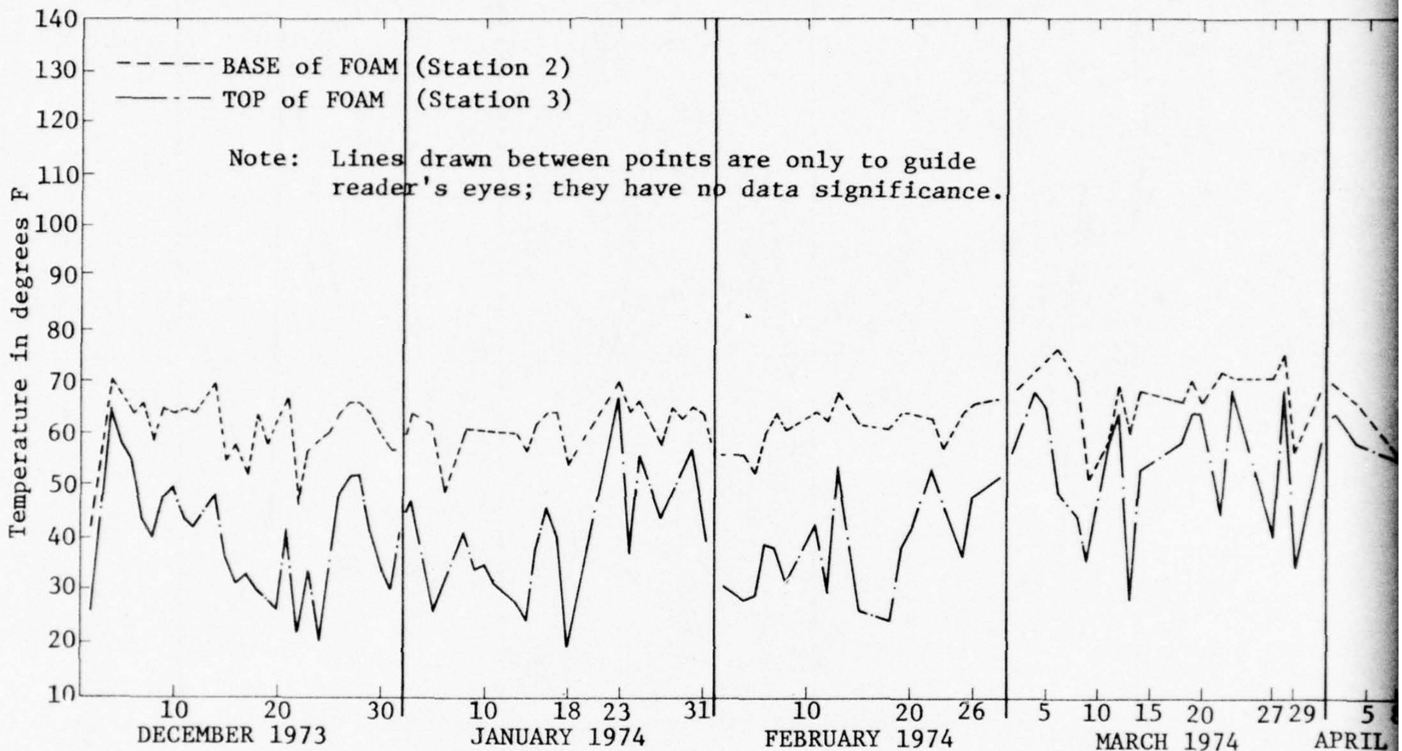
2



(b) Moisture-Curing Silicone Coating (System 2)

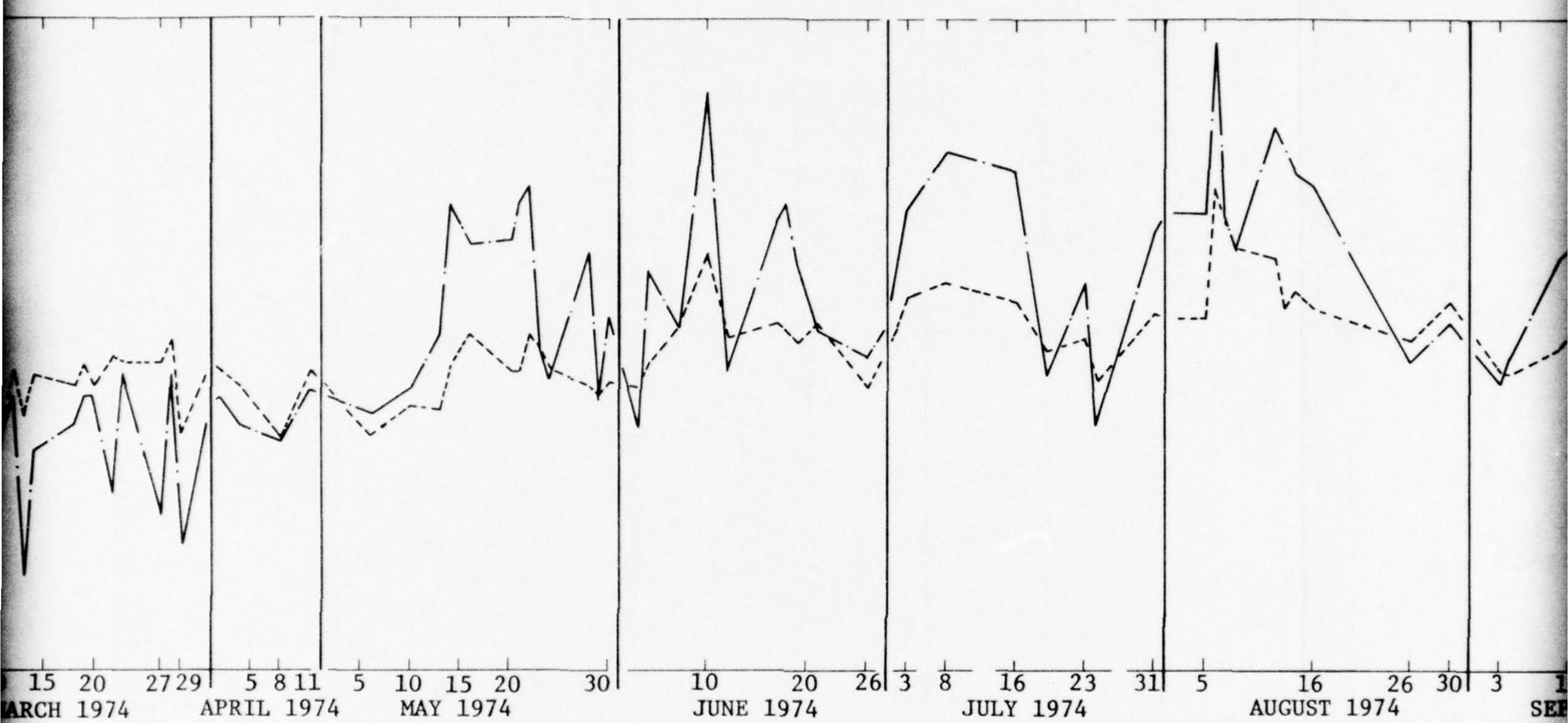
Figure 18. Continued


8 16 24 31
JULY 1974
5 10 16 26 30
AUGUST 1974
3 5 9 15 20 30
SEPTEMBER 1974
3 5 10 15 27 31
OCTOBER 1974
6 10 15 22
NOVEMBER 1974



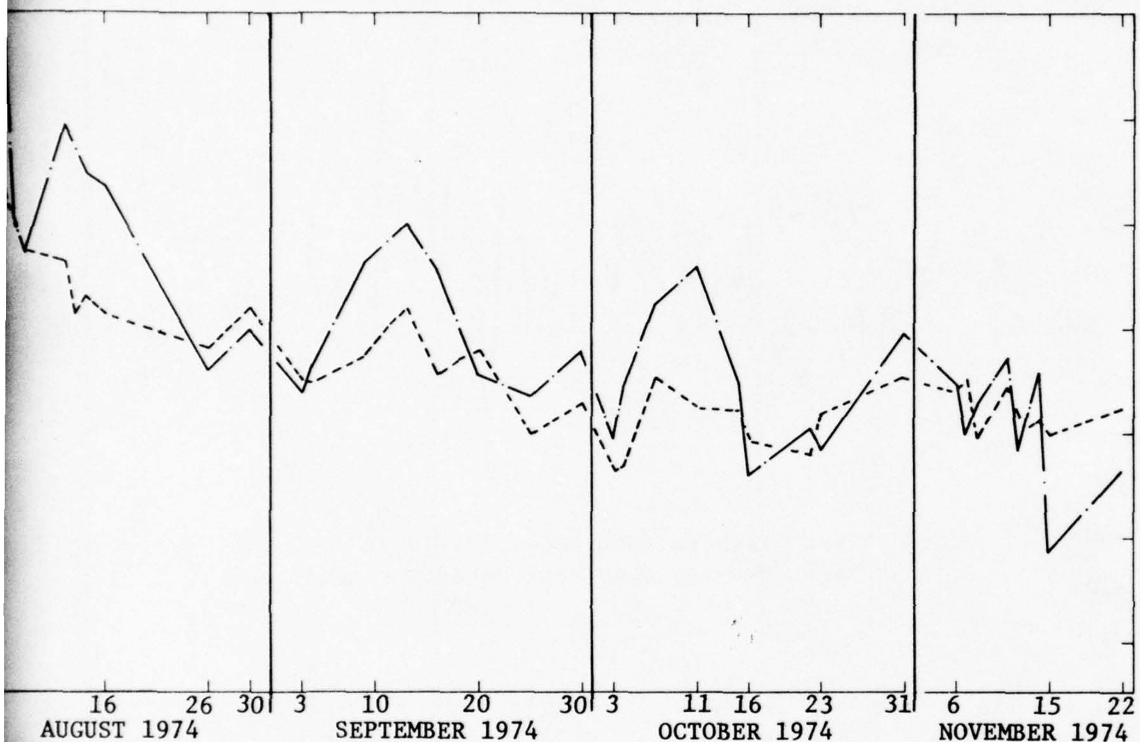
140
130
120
110
100
90
80
70
60
50
40
30
20
10
Temperature in degrees F
BASE of FOAM (Station 2)
TOP of FOAM (Station 3)
Note: Lines drawn between points are only to guide reader's eyes; they have no data significance.
10 20 30
DECEMBER 1973
10 18 23 31
JANUARY 1974
10 20 26
FEBRUARY 1974
5 10 15 20 27 29
MARCH 1974
5
APRIL

2

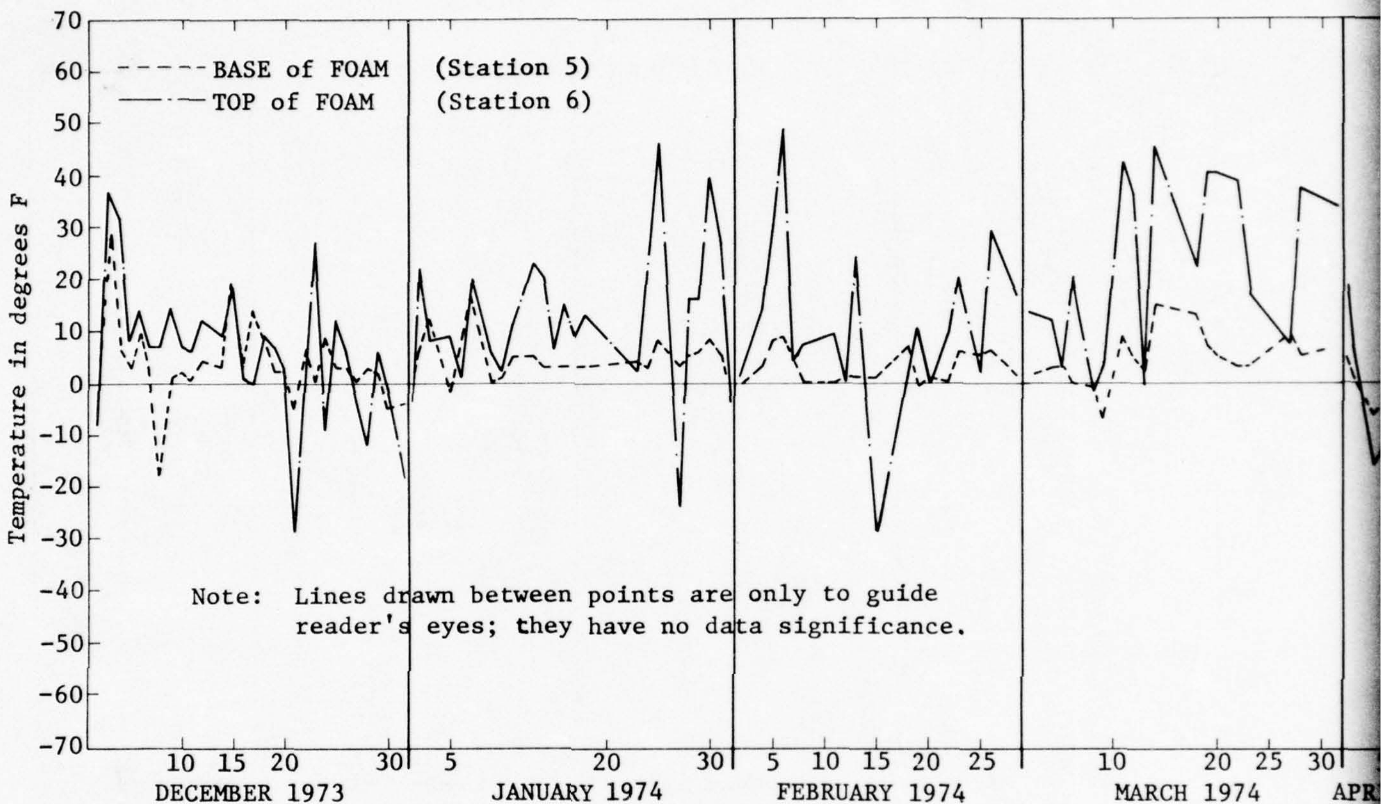


(c) Catalyzed Butyl-Hypalon Coating (System 5)

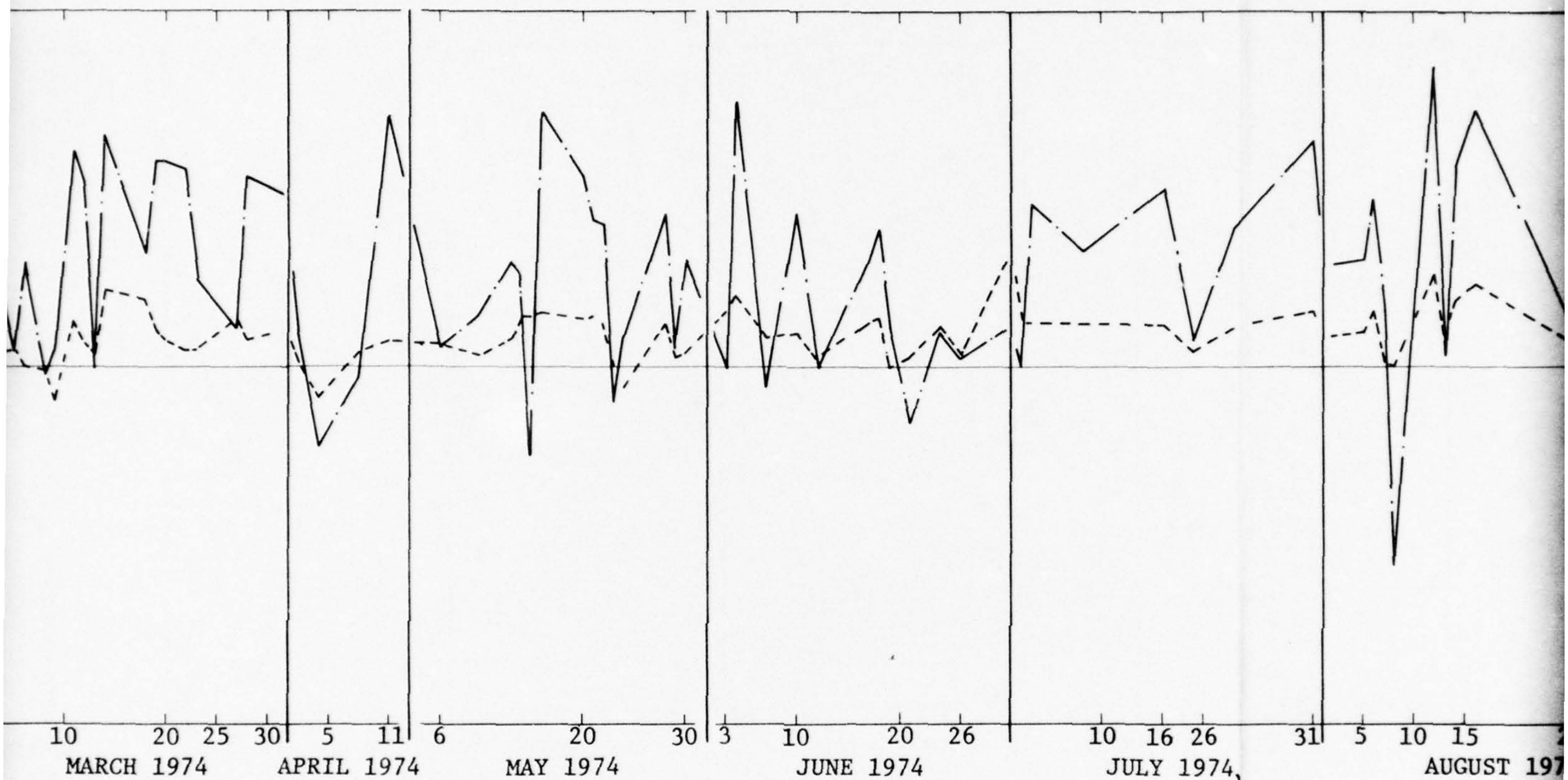
Figure 18. Continued


16
26
30
3
10
20
30
3
11
16
23
31
6
15
22
AUGUST 1974
SEPTEMBER 1974
OCTOBER 1974
NOVEMBER 1974

3

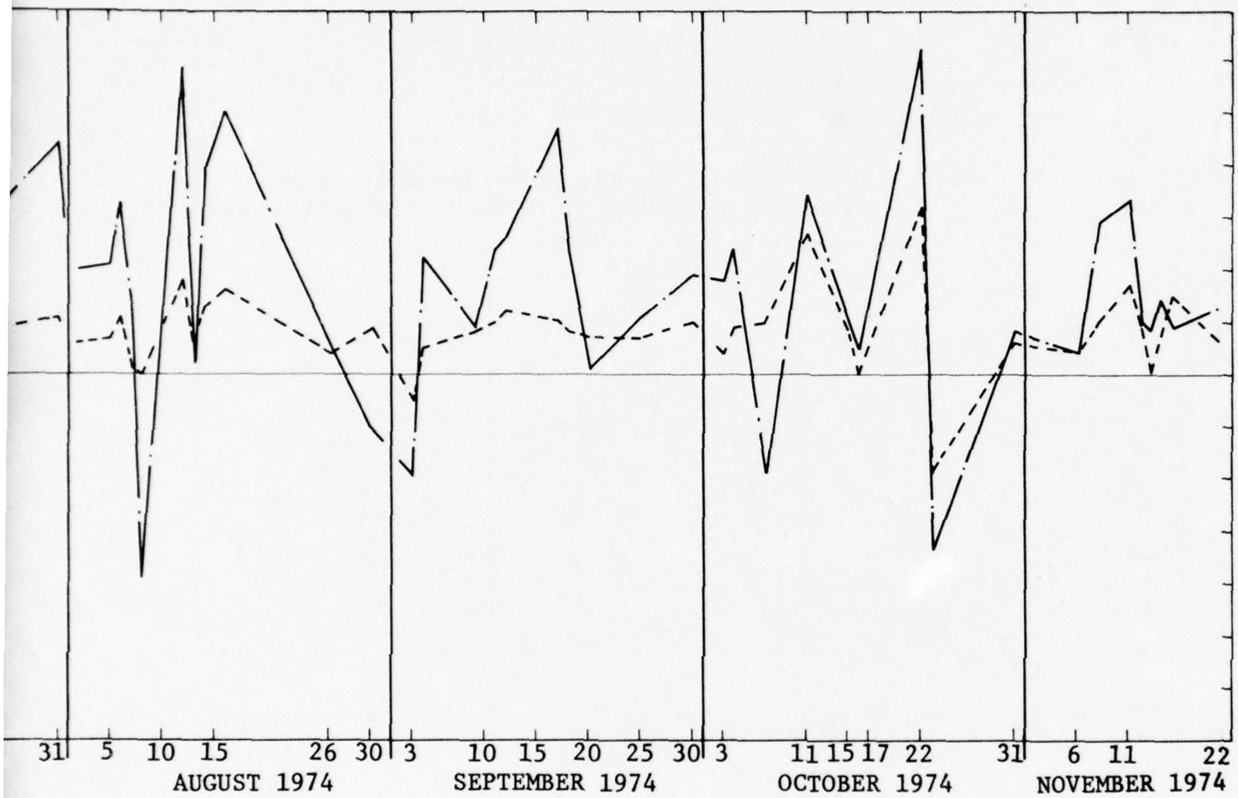

BASE of FOAM (Station 5)
TOP of FOAM (Station 6)
Temperature in degrees F
Note: Lines drawn between points are only to guide reader's eyes; they have no data significance.
DECEMBER 1973
JANUARY 1974
FEBRUARY 1974
MARCH 1974

2



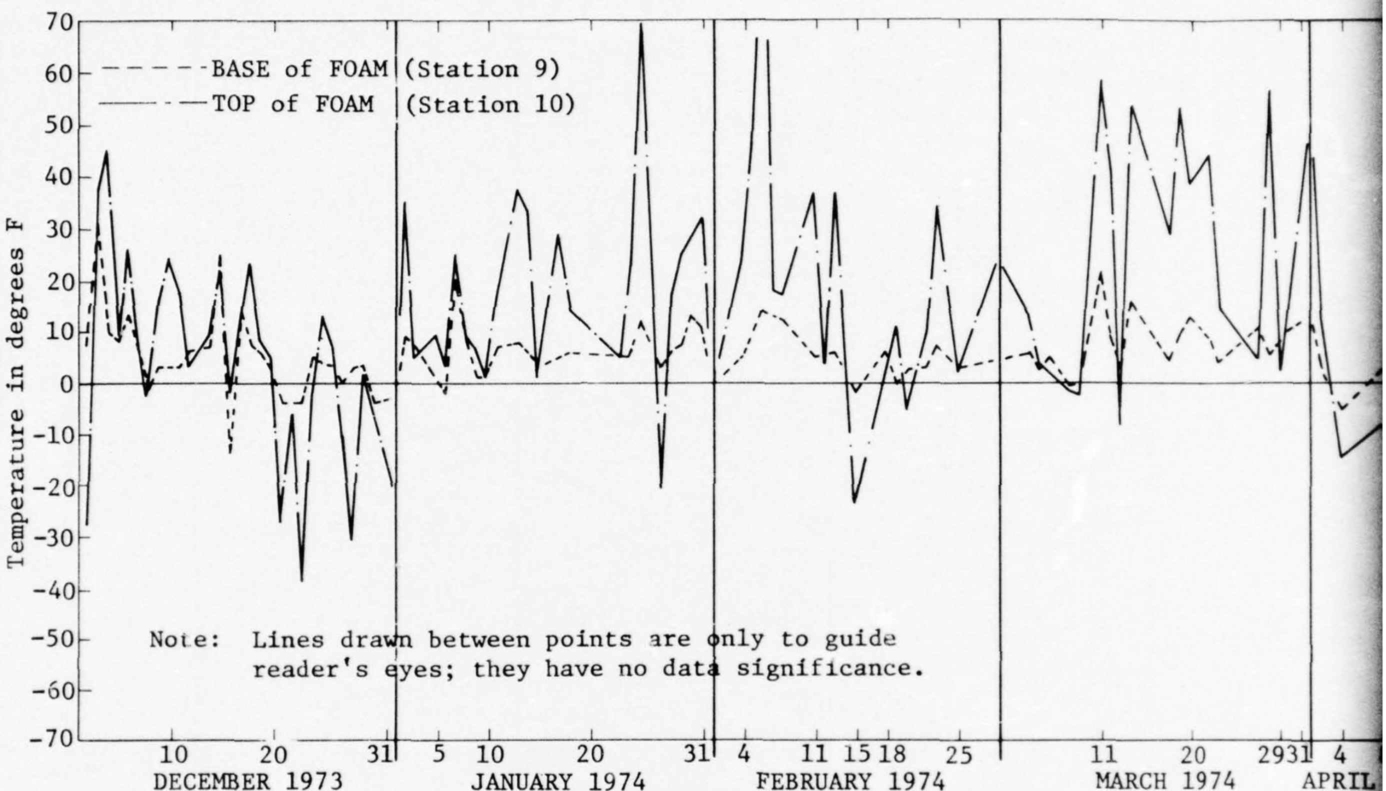
(a) Hypalon Mastic (System 4)

Figure 19. Daytime Temperature Differences



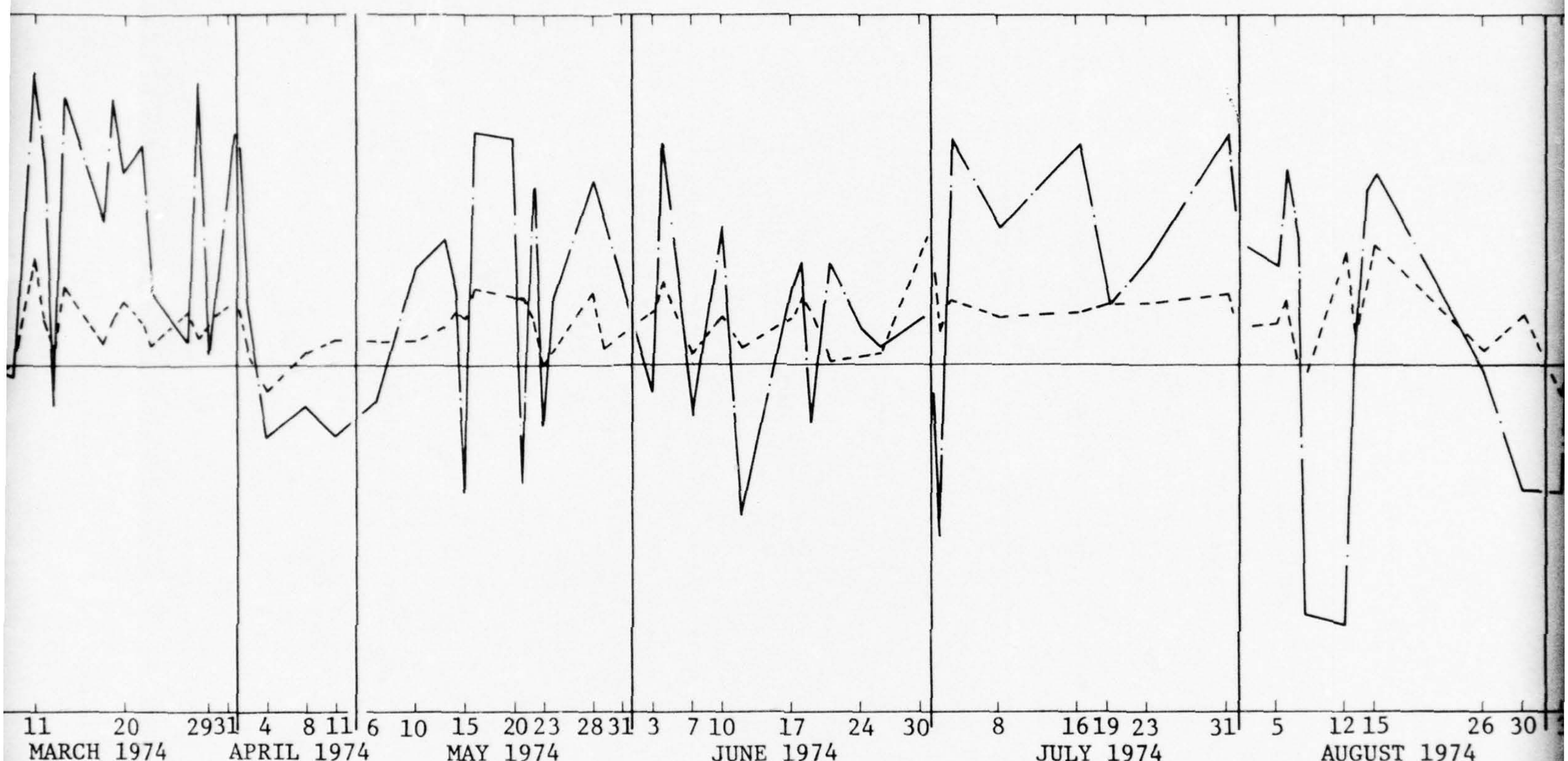
31
5 10 15 26 30
AUGUST 1974
3 10 15 20 25 30
SEPTEMBER 1974
3 11 15 17 22 31
OCTOBER 1974
6 11 22
NOVEMBER 1974

3



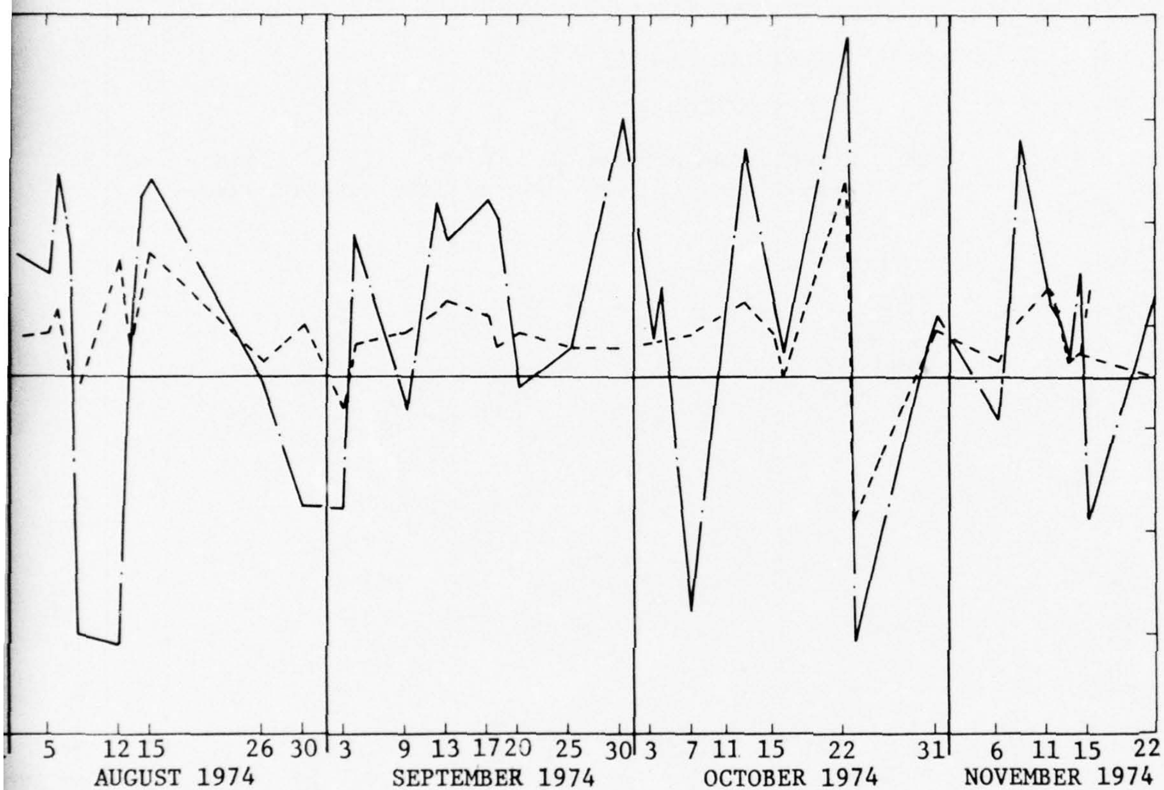
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
Temperature in degrees F
BASE of FOAM (Station 9)
TOP of FOAM (Station 10)
Note: Lines drawn between points are only to guide reader's eyes; they have no data significance.
10 20 31
DECEMBER 1973
5 10 20 31
JANUARY 1974
4 11 15 18 25
FEBRUARY 1974
11 20 29 31
MARCH 1974
4
APRIL

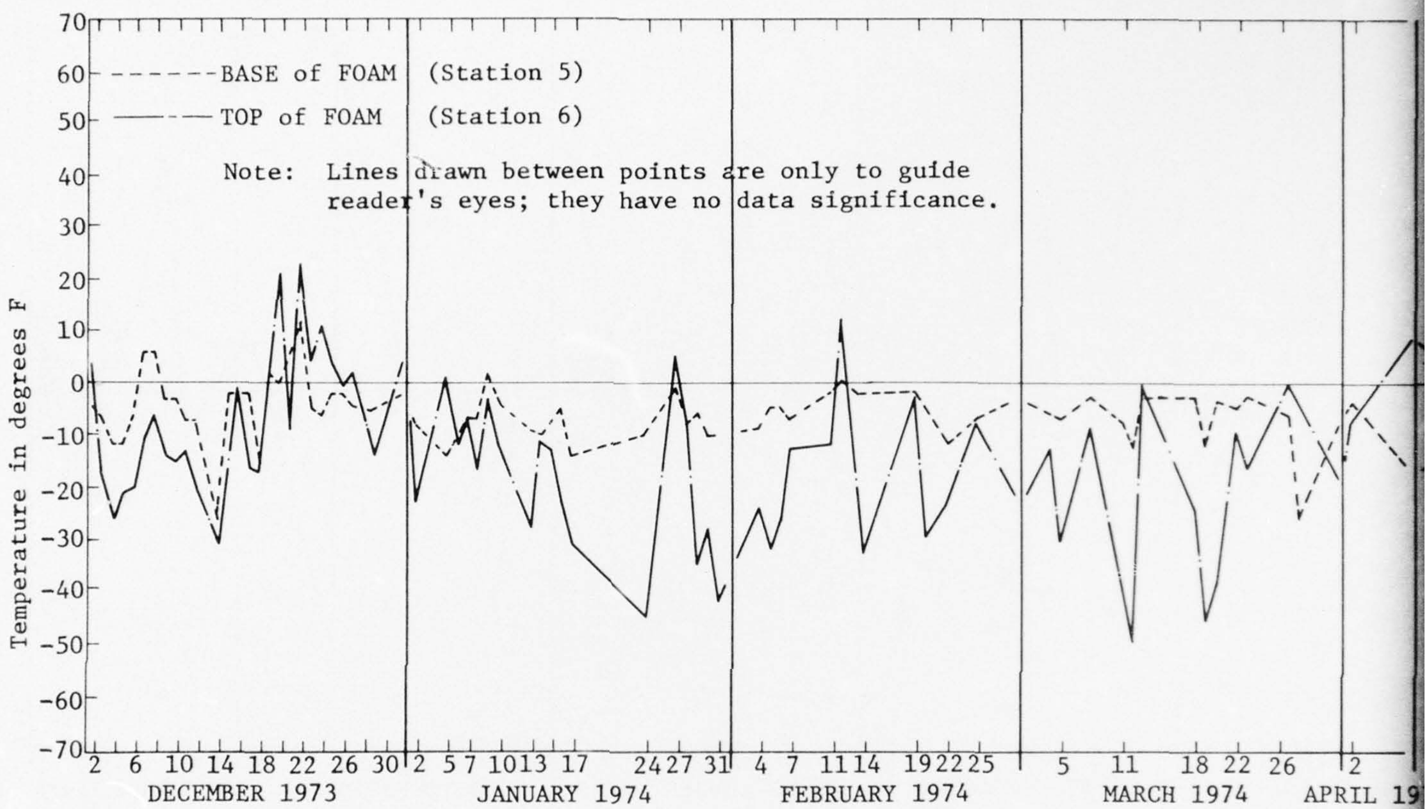
2



(b) Catalyzed Butyl-Hypalon (System 3)

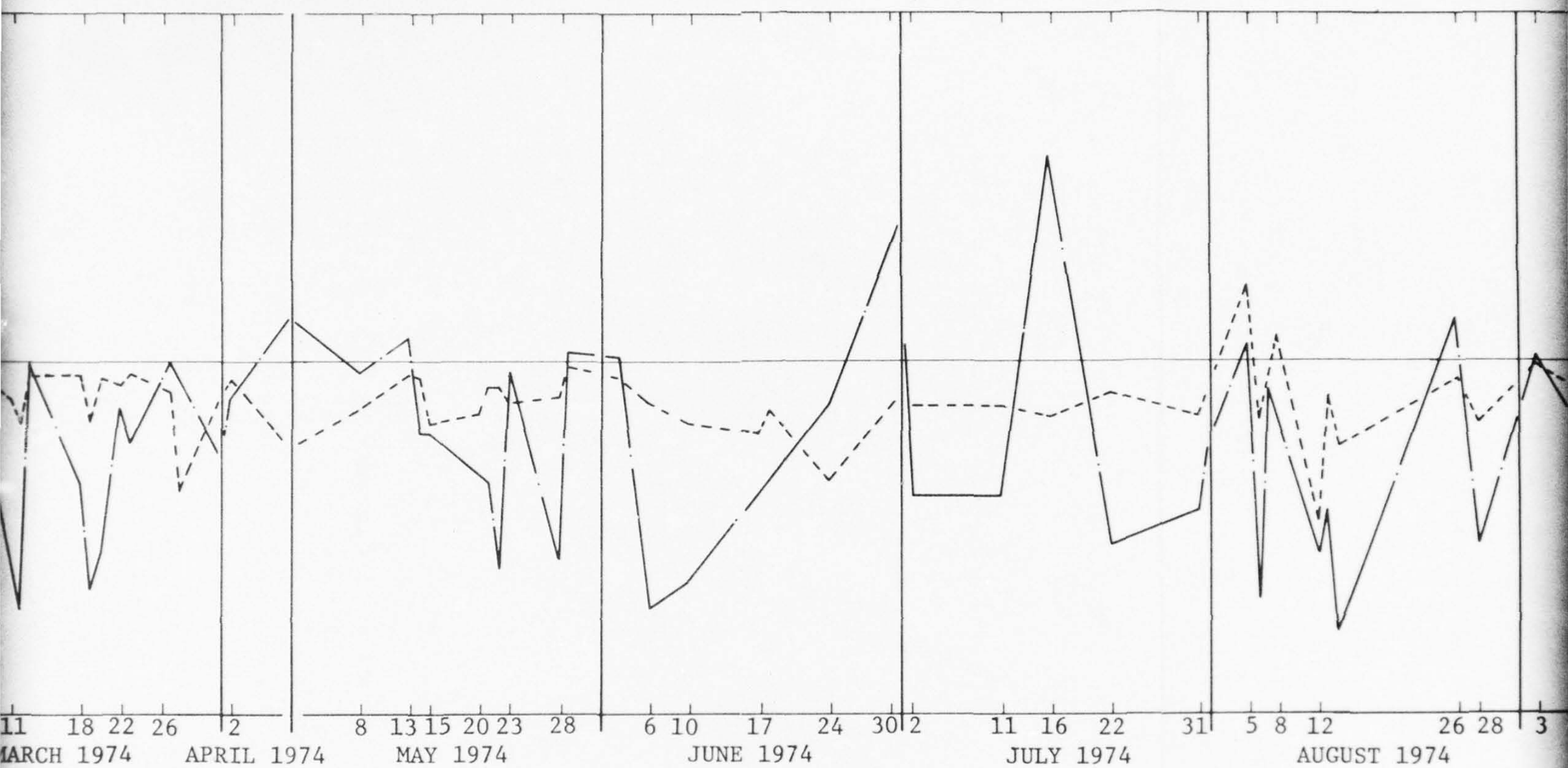
Figure 19. Continued


5
12 15
26
30
3
9
13
17
20
25
30
3
7
11
15
22
31
6
11
15
22
AUGUST 1974
SEPTEMBER 1974
OCTOBER 1974
NOVEMBER 1974



BASE of FOAM (Station 5)
TOP of FOAM (Station 6)
Note: Lines drawn between points are only to guide reader's eyes; they have no data significance.
Temperature in degrees F
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
2 6 10 14 18 22 26 30
DECEMBER 1973
2 5 7 10 13 17 24 27 31
JANUARY 1974
4 7 11 14 19 22 25
FEBRUARY 1974
5 11 18 22 26
MARCH 1974
2
APRIL 19

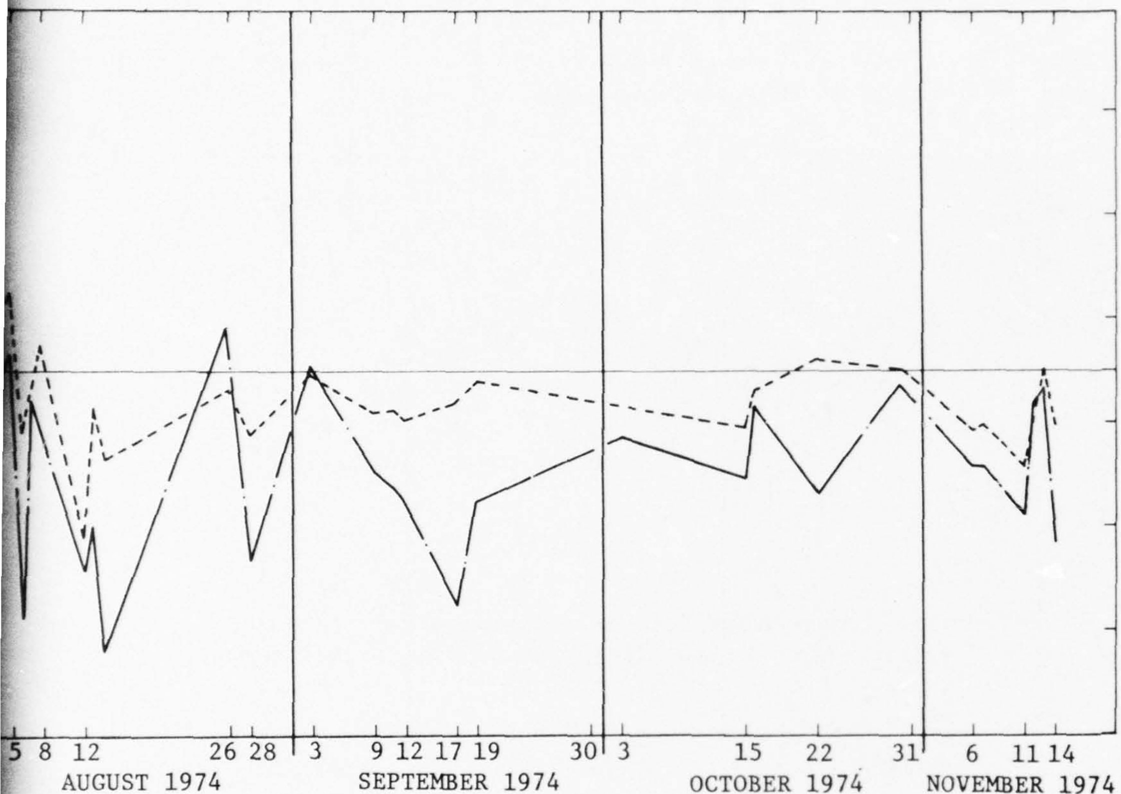
2

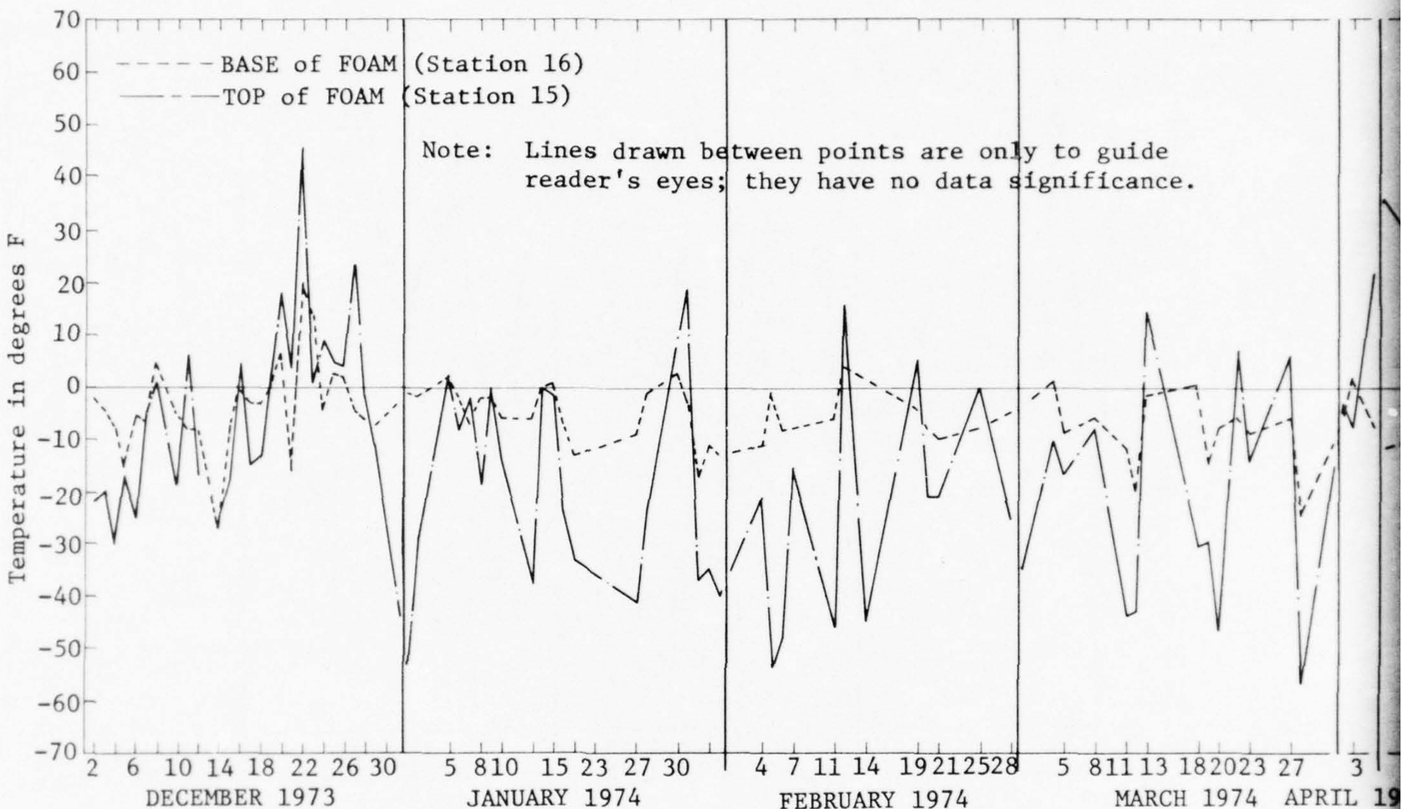


(a) Hypalon Mastic (System 4)

Figure 20. Overnight Temperature Differences

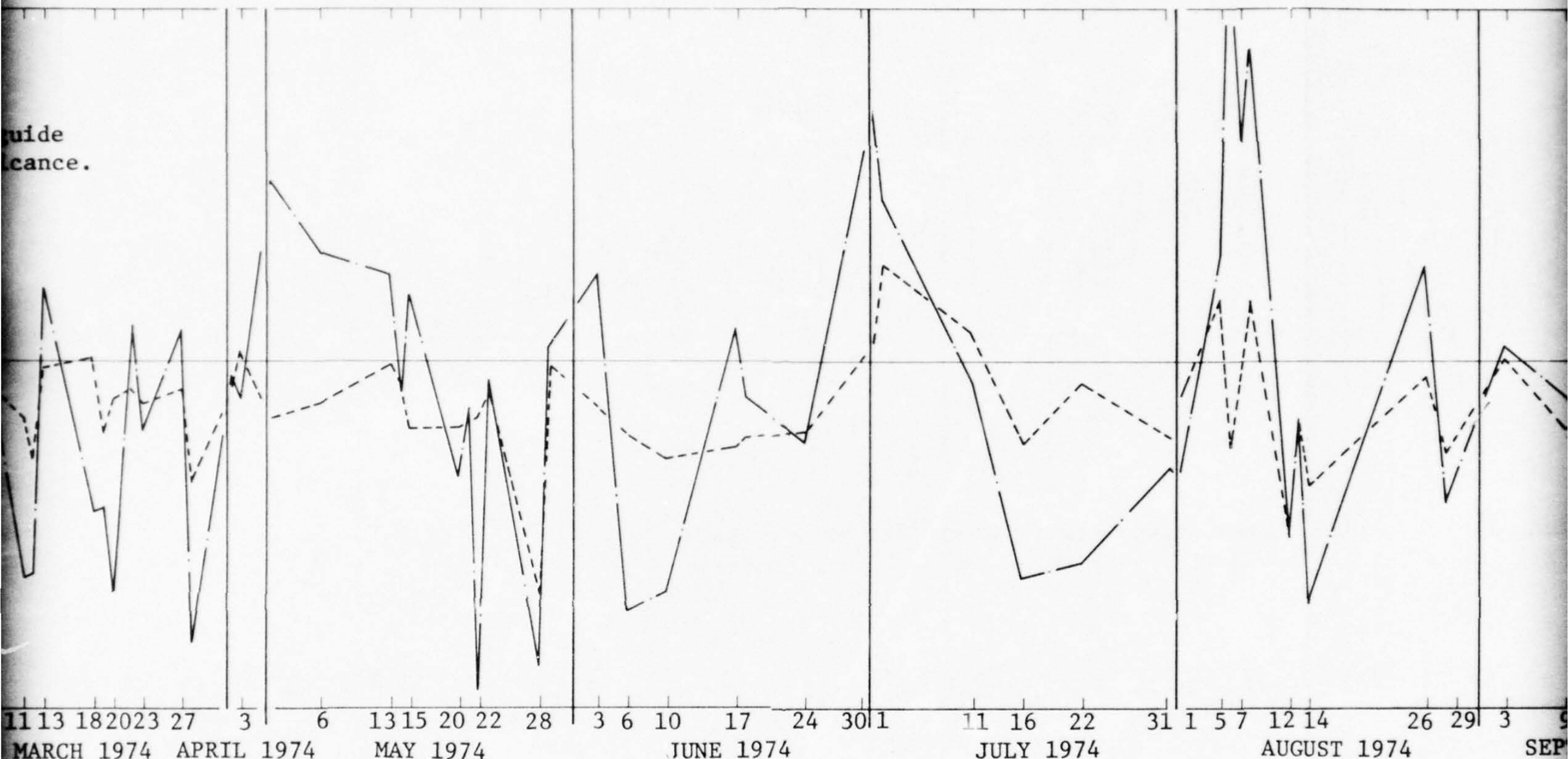
3


5 8 12 26 28 3 9 12 17 19 30 3 15 22 31 6 11 14
AUGUST 1974
SEPTEMBER 1974
OCTOBER 1974
NOVEMBER 1974



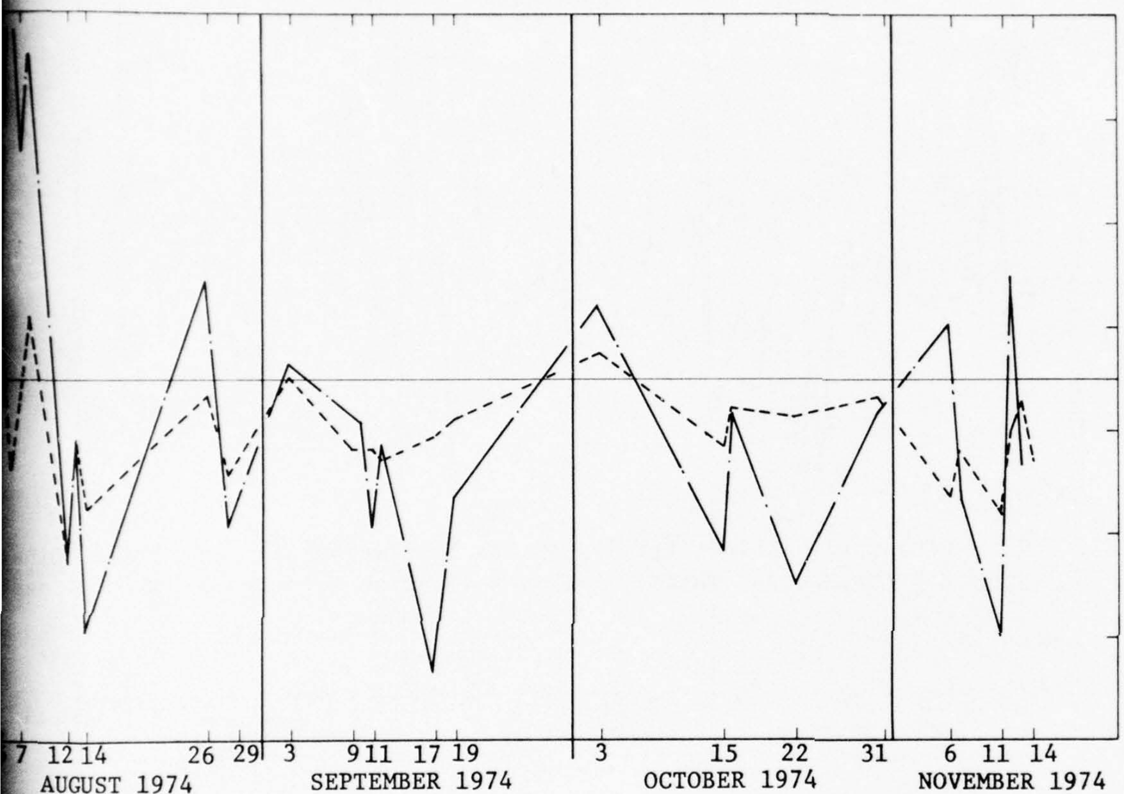
BASE of FOAM (Station 16)
TOP of FOAM (Station 15)
Note: Lines drawn between points are only to guide reader's eyes; they have no data significance.
Temperature in degrees F
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
2 6 10 14 18 22 26 30
DECEMBER 1973
5 8 10 15 23 27 30
JANUARY 1974
4 7 11 14 19 21 25 28
FEBRUARY 1974
5 8 11 13 18 20 23 27
MARCH 1974
3
APRIL 19

2



(b) Moisture-Curing Silicone (System 2)

Figure 20. Continued


7 12 14 26 29 3 9 11 17 19 3 15 22 31 6 11 14
AUGUST 1974
SEPTEMBER 1974
OCTOBER 1974
NOVEMBER 1974

3

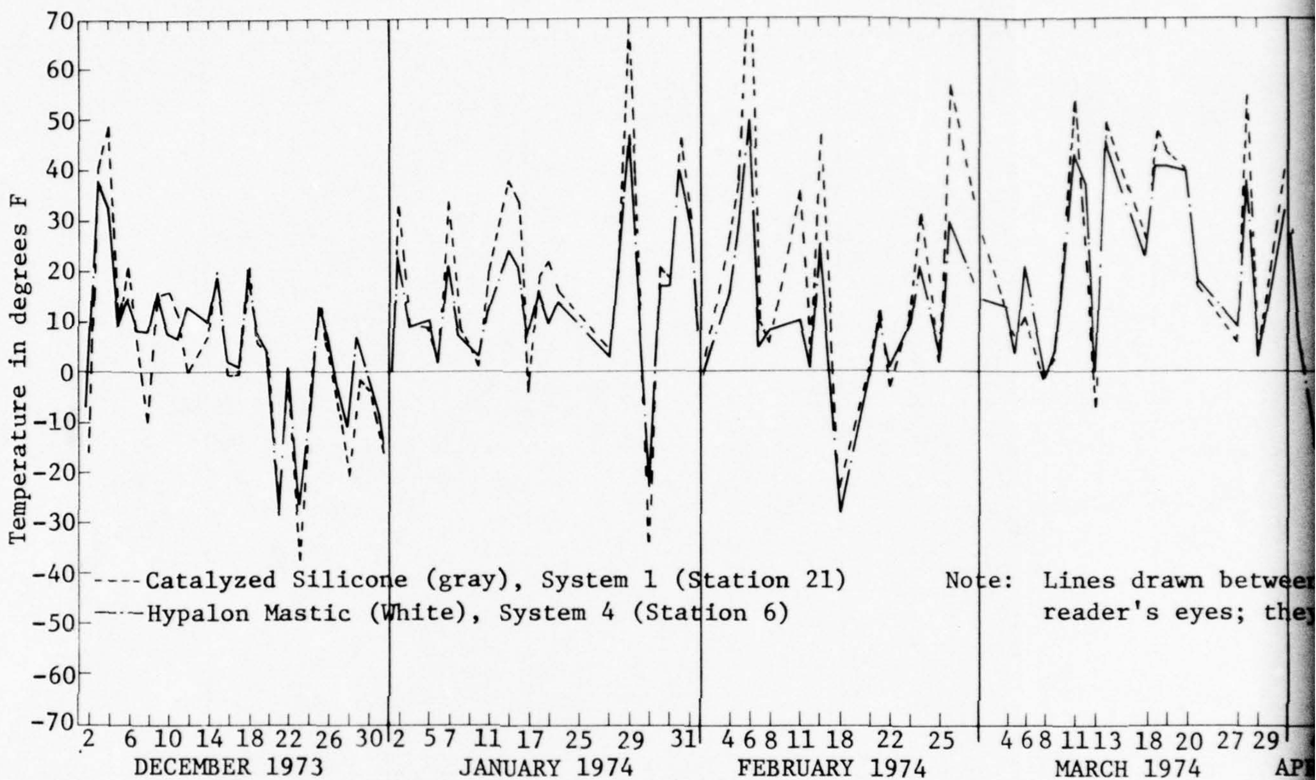


Figure 21. Top
Sys

2

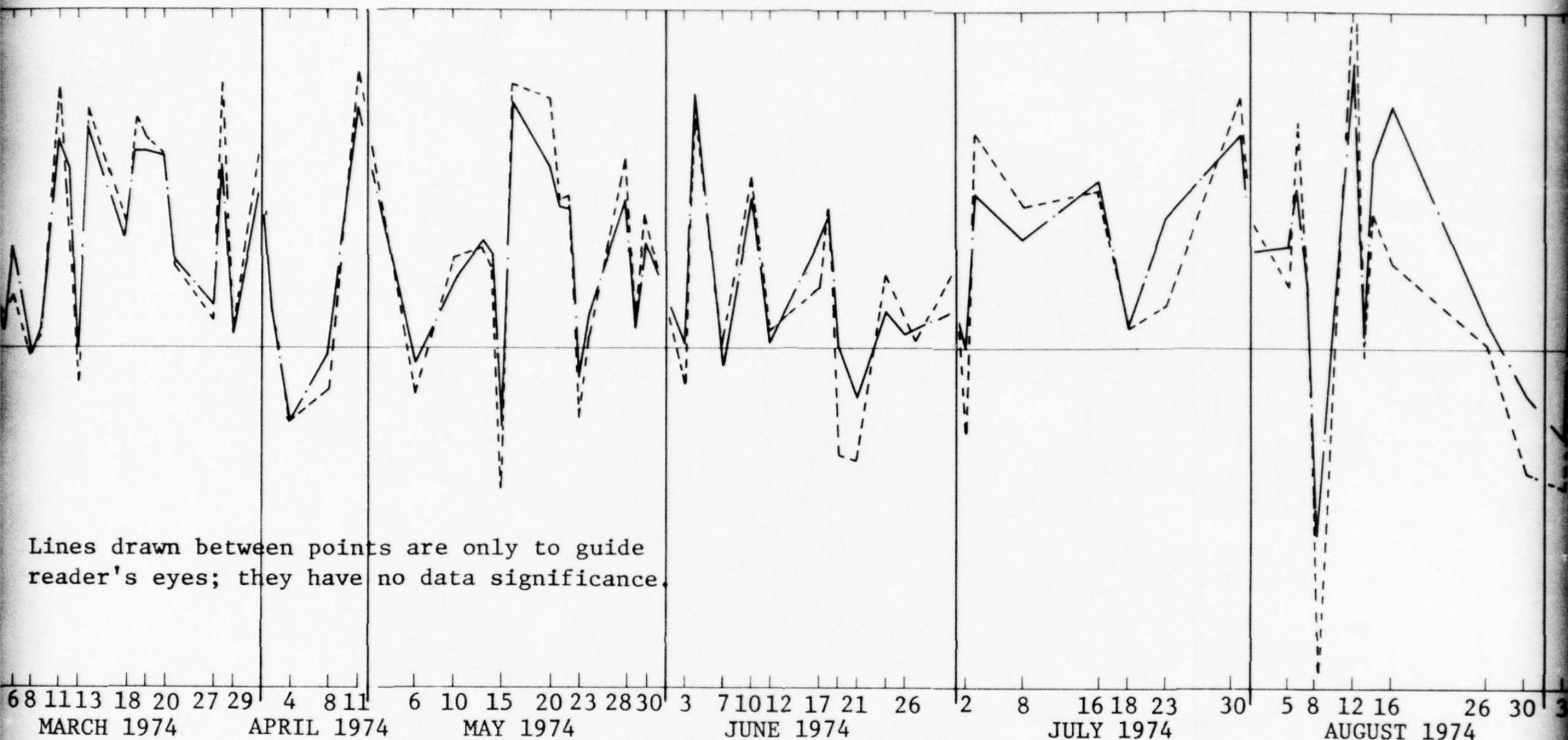
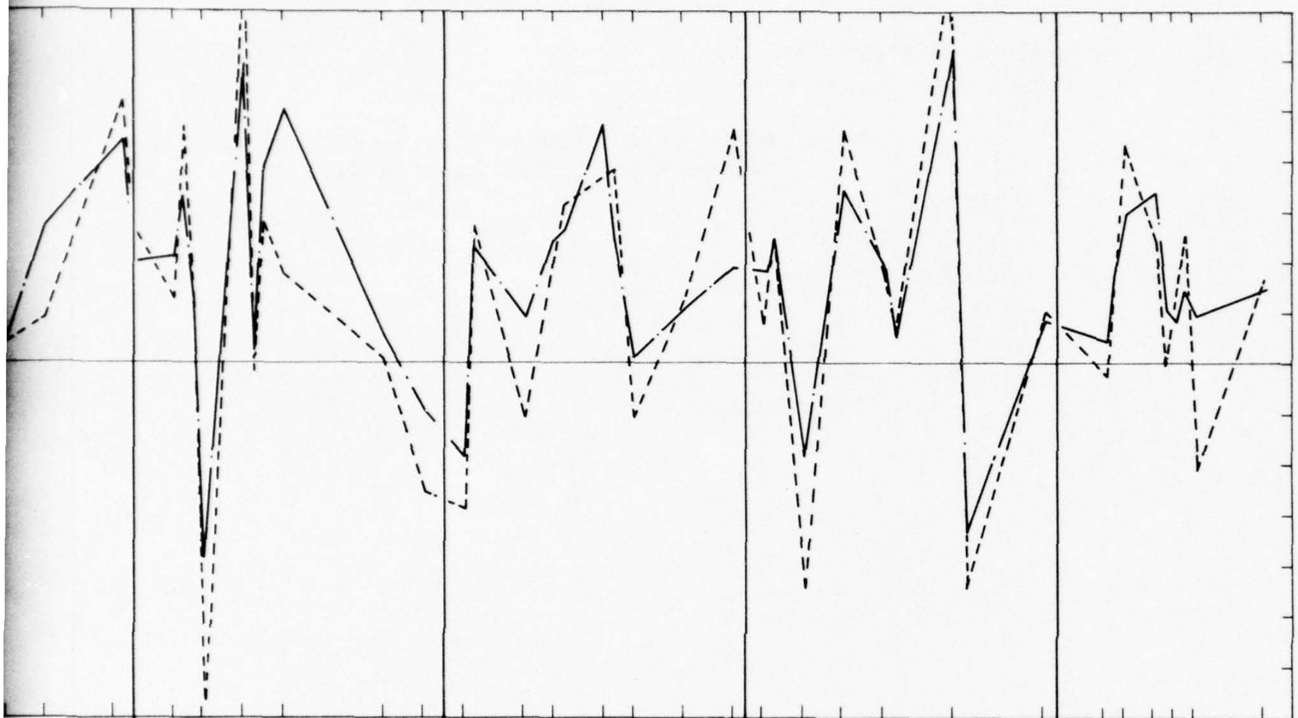


Figure 21. Top-of-foam Daytime Temperature Differences for Catalyzed Silicone Rubber (gray), System 1, and Hypalon Mastic (white), System 4



one Rubber (gray),

3

NORDIVNAVFAC personnel. Inspections have been conducted biannually; the first in early spring (April) following the winter season, and the second during or near the end of the summer season (July or August). Thus, on-site inspections of the roofs have been made after 6, 9, 18, and 22 months of weathering. The inspections consist of walking all areas of the roofs and recording and photographing any deterioration of coatings or foam. Photomacrographs of selected areas are also taken during each inspection in order to have a progressive record of any deterioration.

Ratings were assigned to each system during each inspection. Explanation of the ratings is shown below:

E = Excellent; the system is in excellent condition with little or no coating or foam deterioration.

VG = Very good; the system is performing very well and shows only minor coating or foam deterioration.

G = Good; the system is performing satisfactorily, but coating or foam deterioration is nearing a point of significance.

F = Fair; the system is showing moderate coating or foam deterioration.

P = Poor; the system has numerous areas showing moderate to severe coating or foam deterioration.

The results of the four inspections to date are presented below and are summarized in Table 5. Note that except for two small areas in which the foam quality was poor, deterioration is first noticeable in the coating. Generally speaking, as long as the coating performs well, the foam can be expected to perform well also. In areas where the coating degrades or flakes off and exposes the foam, the foam will also be degraded by exposure to the weather. Thus, the ratings for all practical purposes reflect the condition of the coating system on the roof. It should be emphasized that even where the coating systems are not performing well, the experimental roof systems have not leaked since the foam was applied. About 6 months after the roof was installed, NRC personnel reported a leak in the South Building. However, further investigation showed that it was not a leak in the foam roof, but that water was being blown into the attic area of the South Building through an opening at the junction of the Boiler House and the South Building, i.e., underneath the eaves. The East side of the junction can be seen in Figure 22. These roof junctions were waterproofed during roof repairs, which are discussed in the next section.

System 1. Catalyzed Silicone Rubber

This system was divided into two sections: one with granules and one without granules. The portion with granules has performed very well

Table 5. Performance of Coated Polyurethane Foam Roofing Systems

System Number and Description	Performance Rating[a] After -				Remarks Relating to 22-Month Inspection
	6 Months	9 Months	18 Months	22 Months	
1. Catalyzed silicone rubber with granules	E	E	E	E	Coating with granules in slightly better condition; no hail damage observed on either section of this system.
without granules.	E	VG to E	VG	VG	
2. Moisture-curing silicone rubber	E	VG to E	VG	VG	Very comparable in performance to System 1 section without granules; deterioration limited to a few very small, scattered areas where coating removed and foam degrading.
3. Catalyzed butyl-hypalon	G	F	P to F	P	Coating has deteriorated to point of near failure in many areas due to severe checking, cracking, erosion, and hail damage.
4. Hypalon mastic	VG to E	G to VG	G	P to F	Most severe deterioration is due to hail damage; also has severe erosion of coating, exposing foam on south side of roof.
5. Catalyzed butyl-hypalon	E	VG to E	VG	F to G	Coating exhibited only very light, scattered deterioration until hail damage occurred.

a) Ratings were assigned as follows: E = Excellent; VG = Very Good; G = Good; F = Fair; and P = Poor.

throughout the entire duration of the experiment. The only deterioration noted has been flaking-off of the coating in a few very small spots, exposing the foam. These small imperfections were considered insignificant at the 22-month inspection; therefore, the portion of the catalyzed silicone rubber coating with granules was rated excellent.

The catalyzed silicone rubber coating without granules has also performed very well, although not quite as well as the area with granules. Overall performance of this section was rated as very good. Two small problems occurred in this section. The first of these was noted during the 6-month inspection as a sponginess of the foam in a small area of about one square foot, and is shown after 9 months in Figure 23. Sponginess of this sort is characteristic of foam produced by unequal proportioning of foam components during spray application, and was probably caused by a malfunction of the foam spray unit proportioners. In such an instance, the foam applicator is generally aware of the faulty foam as soon as it is applied. This area and a similar larger area in the System 3 section were both replaced by the contractor within the first year following roof construction. (These repairs are described in more detail later.) However, as indicated in Figure 24, the catalyzed silicone rubber coating over the replaced foam is exhibiting serious deterioration after 1 year. It may have been that insufficient coating was applied or that the coating had exceeded its pot-life before application.

The ROICC authorized the addition of an aluminum gravel stop along the fascia edge of the roofline to improve appearance. The configuration of the gravel stop caused ridges in the foam in two places along and adjacent to the eaves of the roofs of both the North and South Buildings. This ridging in effect provided two areas along the eaves for small amounts of ponding water (Figure 25). While ponded water is always a potentially serious problem, it has caused no noticeable deterioration of any of the systems to date.

It has been reported that bird-pecking has caused problems with many foam roofs. It has not been a serious problem with the experimental roof systems at the Reserve Center, but two bird-pecked areas have been observed. One of these areas is shown in Figure 26. Note that the size is less than 1 square inch.

System 2. Moisture-Curing Silicone Rubber

During the winter months of 1973-1974, snow accumulated on the test roofs more heavily than in the past, probably because the roofs are well insulated by the foam from interior building heat. Due to the inherent slipperiness of the silicone coatings when wet, the snow and ice combination slid down and off the roof of the North Building essentially in one huge sheet as thawing occurred. This action clipped coating off of some small high points, exposing the foam (Figure 27). Because of the slipperiness of the silicone, sliding of the mass of snow and ice was more of a problem with Systems 1 and 2 than with the other three systems. It was not a problem in that portion of System 1 having granules.

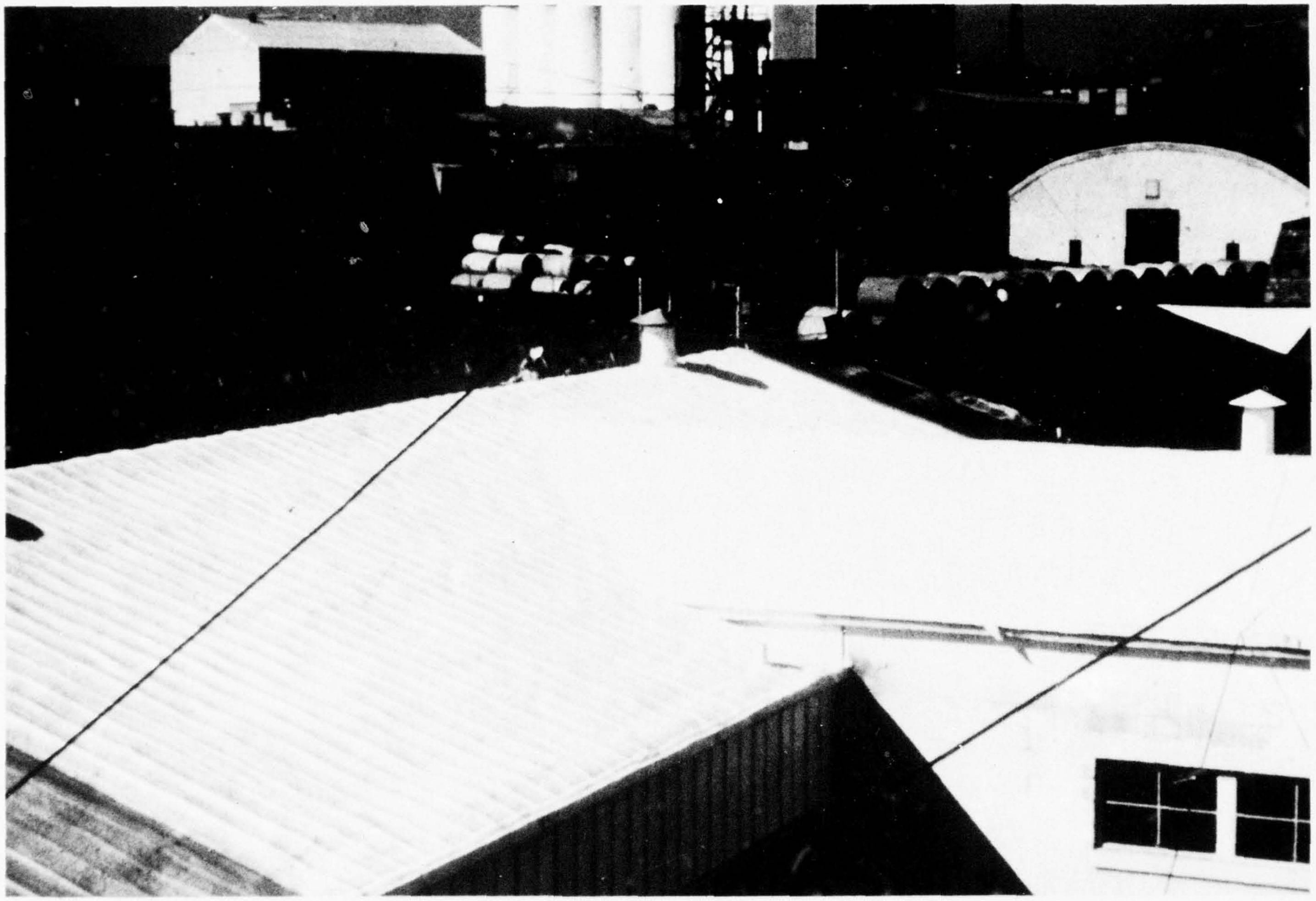


Figure 22. East Side of Junction of Boiler House and South Building

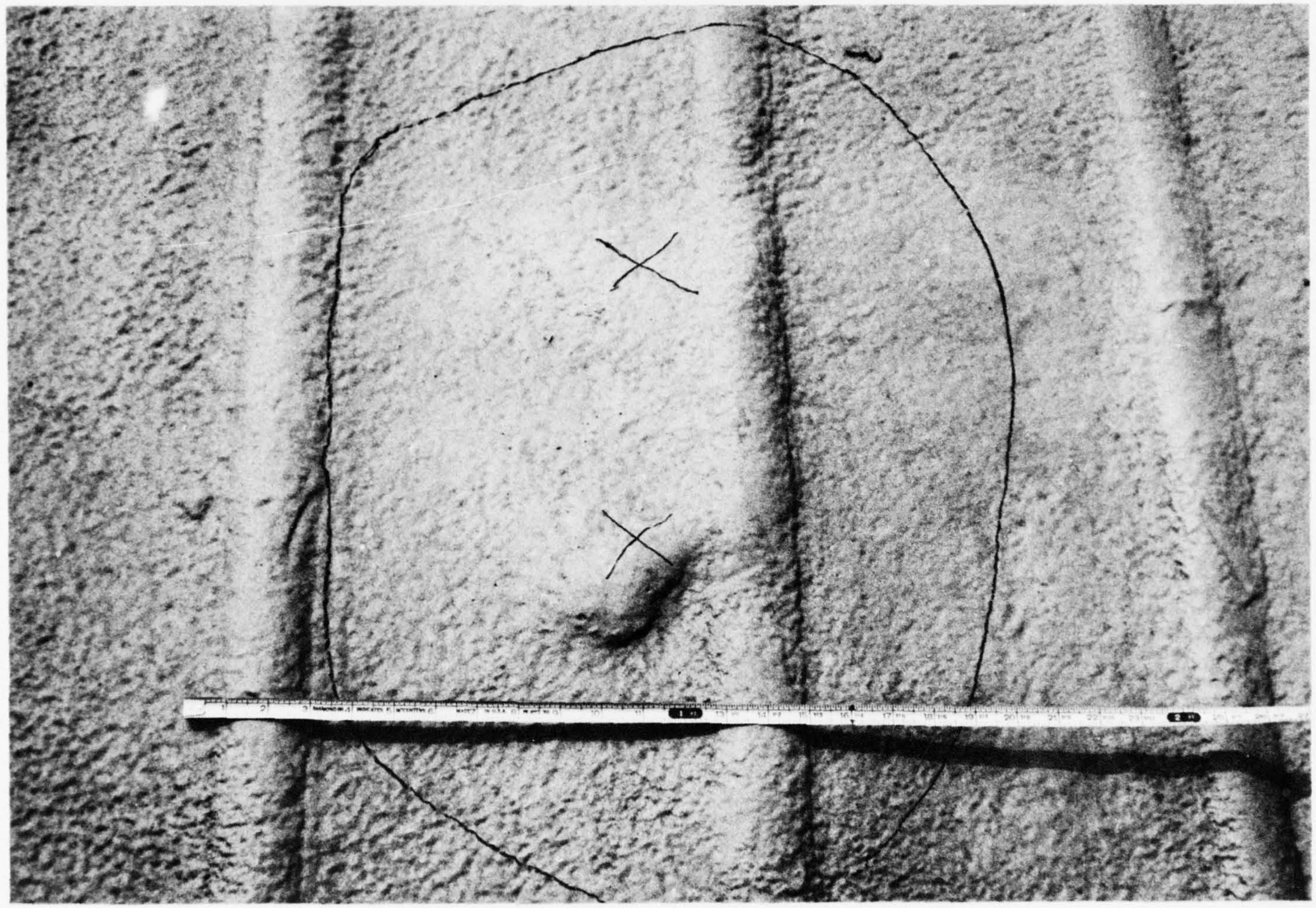


Figure 23. Soft, Spongy Area on North Side of System 1 (Without Granules) After 9 Months Weathering

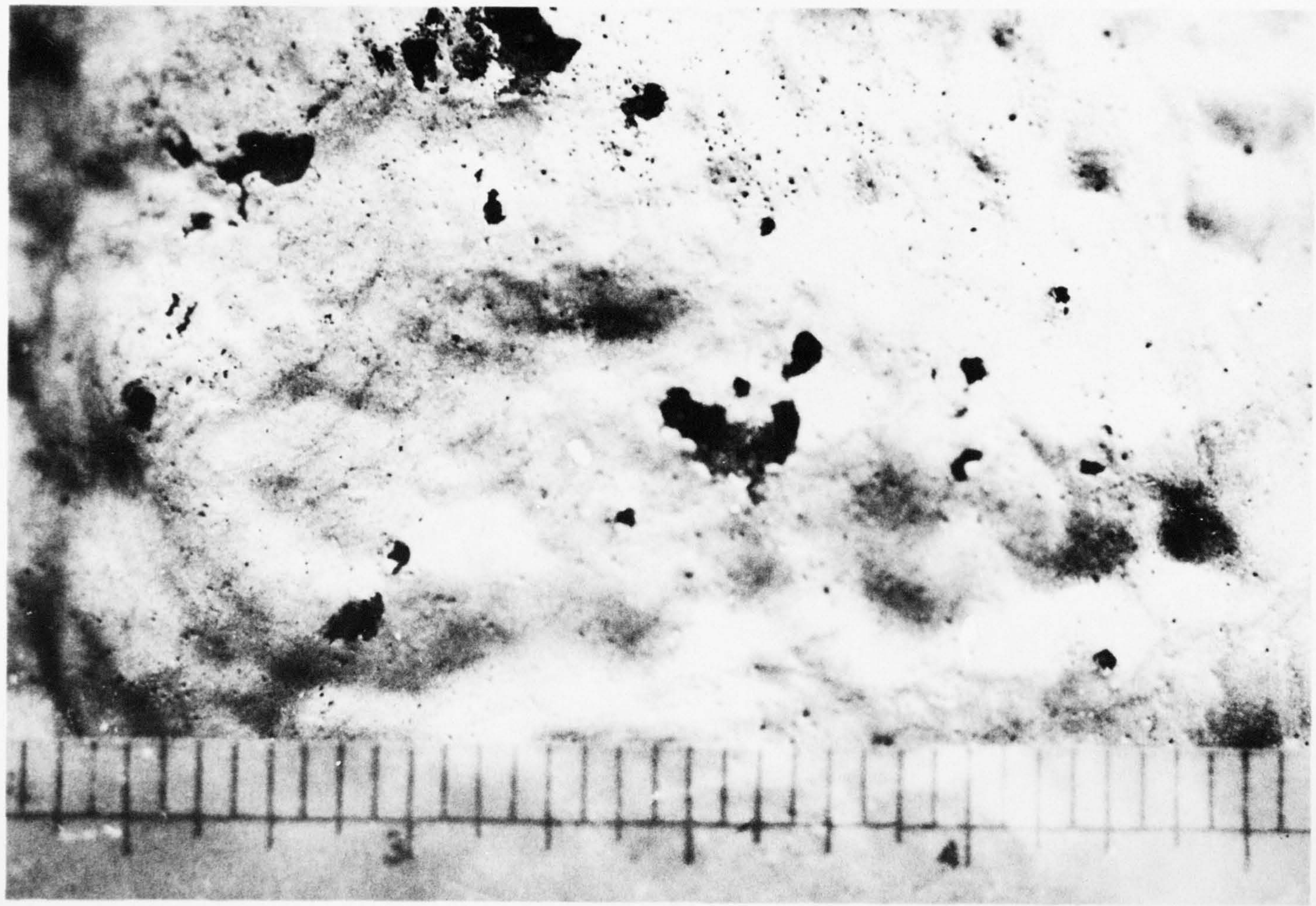


Figure 24. Deteriorating Catalyzed Silicone Rubber Coating Over Replaced Foam 12 Months After Application

Figure 25. Ponded Water Along Gravel Stop in the System 1 Section

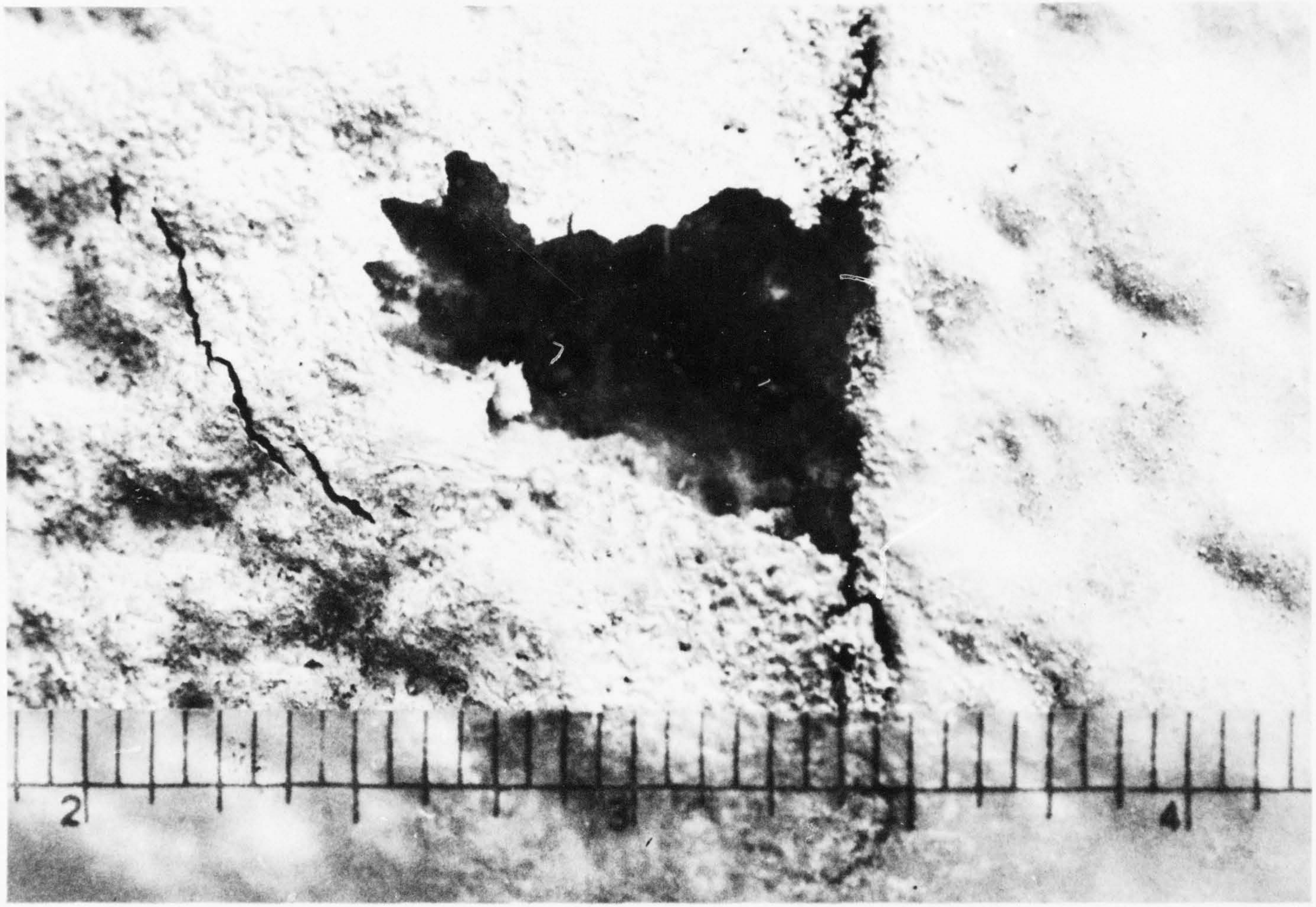


Figure 26. Close-up of Small Area Showing Bird Pecking in System 1 Section After 22 Months of Weathering

Figure 27. Damaged Areas in System 2 Section Caused by Sliding Snow and Ice

Overall, this moisture-curing silicone rubber coating is performing as well as that portion of the catalyzed silicone coating (System 1) without granules. Several things were observed in this section, however, that should be mentioned. One of these was cracking of the silicone coating in the bottom of the depression along the rib where the coating appeared to be thicker than usual, i.e., where it had run off the higher spots into the depression. This phenomenon, which was noticed during the 9-month inspection, was found in a very few isolated places. An example is illustrated in Figure 28, which shows the same crack in the moisture-curing silicone after 9, 18, and 22 months. The crack shown does not appear to be lengthening with time. This appears also to be true with smaller cracks in dimpled recessed areas. Since the silicones are so hydrophobic, it is doubtful that standing water will cause opening or extension of the cracks to allow water to enter the foam.

By nature, silicone rubber coatings are tacky and, therefore, tend to attract and hold dirt. Thus, while the top coat of System 1 was originally cement gray in color and the top coat of System 2 was white, over a period of 22 months both had become a dirty dark gray. The dirt can be removed by washing with a detergent, as shown in Figure 29.

The largest instance of bird-pecking occurred in the System 2 section in a most unusual manner. Rather than pecking through the coating to reach the foam, the birds attacked the foam from underneath the gravel stop. The larger of two of these pecked areas is shown in Figure 30. Their repair is described in the following section.

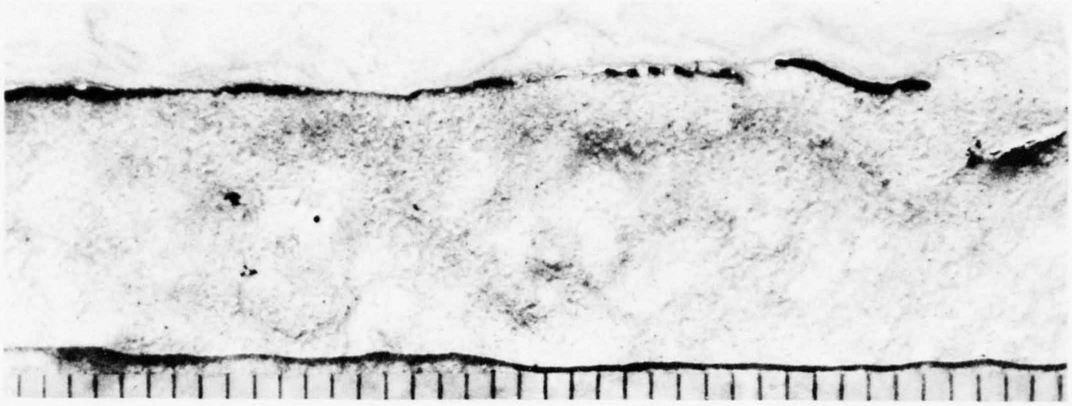
All the above considered, this system was performing very well after 22 months of weathering and was rated very good.

System 3. Catalyzed Butyl-Hypalon

As noted earlier, a number of difficulties were encountered during the application of this system. In particular, the hypalon top coat did not exhibit good hiding characteristics. This was reflected in the performance of the coating system, which showed checking, cracking, and flaking after less than 1 year of exposure. This degradation is shown rather vividly in Figure 31 as it occurred progressively after 9, 18, and 22 months of weathering. Such rapid deterioration suggests the need for recoating this section as soon as possible.

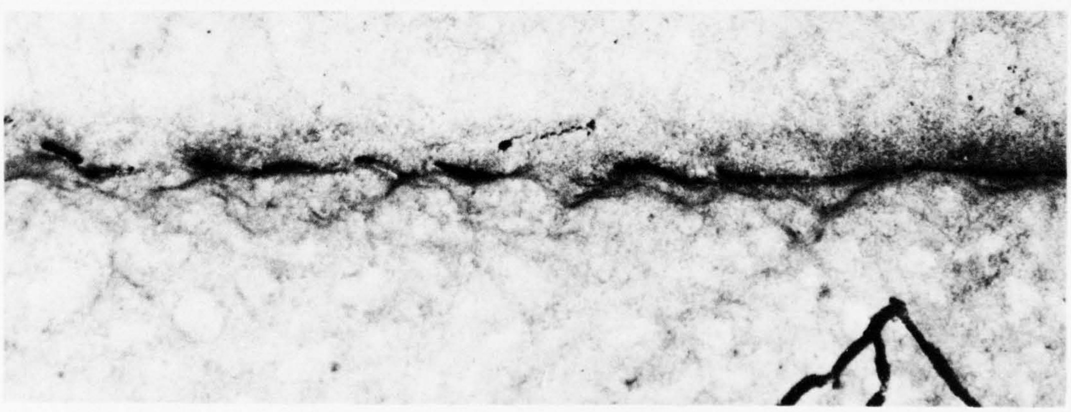
This system also had the largest areas in the experimental roof systems with poor quality foam. These are shown in Figure 32 and Figure 33. Figure 32 shows an area of about 10 square feet of spongy foam, while Figure 33 shows a relatively small area with blistered foam just below the area of spongy foam. In the latter case, the top lift of the foam had blistered from the lift underneath. These areas are believed to have been caused by improper proportioning of components of the foam during application. These areas have also been satisfactorily repaired by the contractor, and their repair is described in a following section.

It was mentioned above that the hiding character of the top coat of this system was rather poor. Because of progressive checking, cracking, and eroding, the hiding quality of the top coat has been further reduced as shown in Figure 34.



(a) After 9 Months of Exposure.

(b) After 18 Months of Exposure.



(c) After 22 Months of Exposure.

Figure 28. Cracking of Moisture-Curing Silicone Rubber Coating in a Depression Along a Rib; Note Cracking Has Not Progressed.

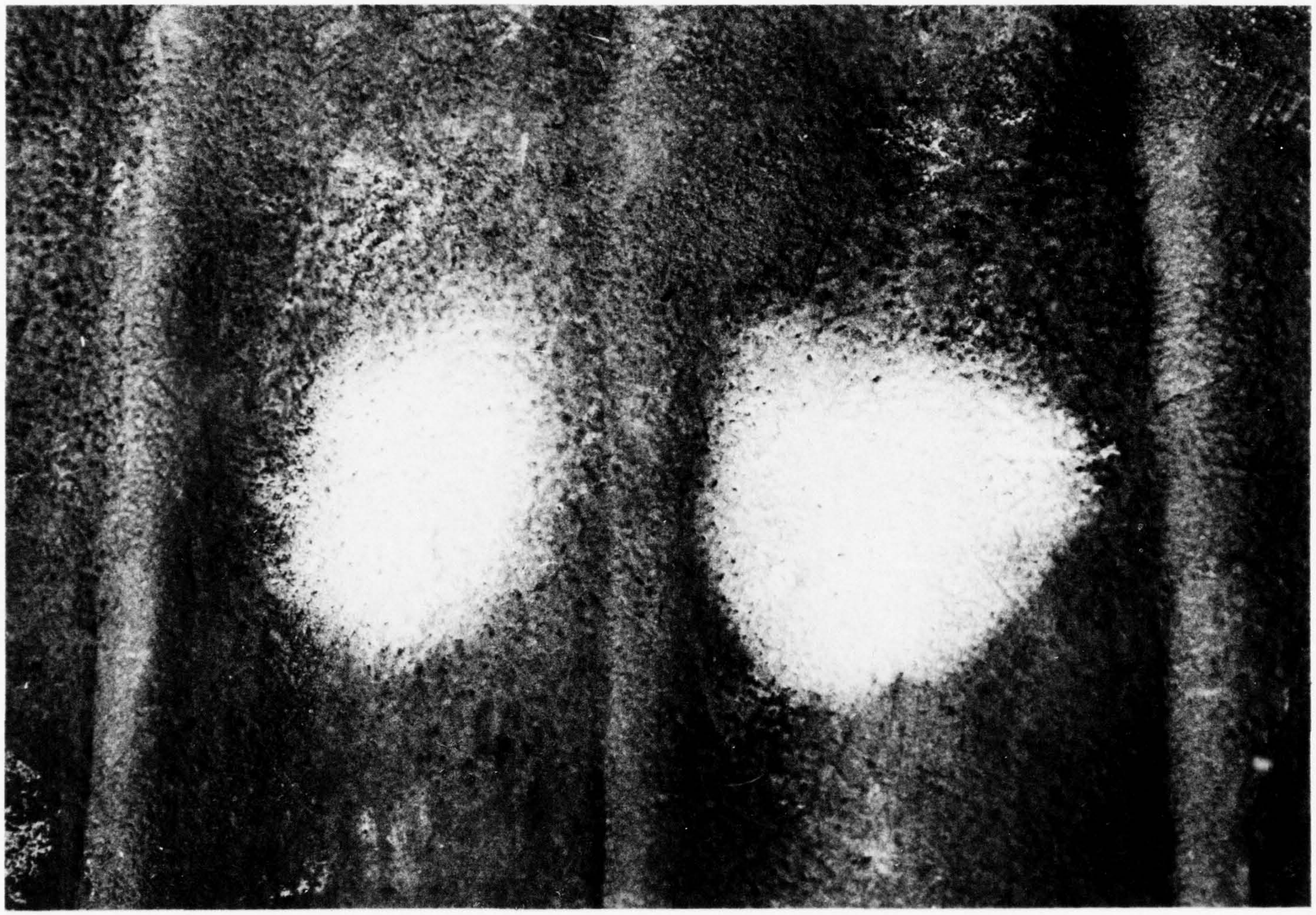
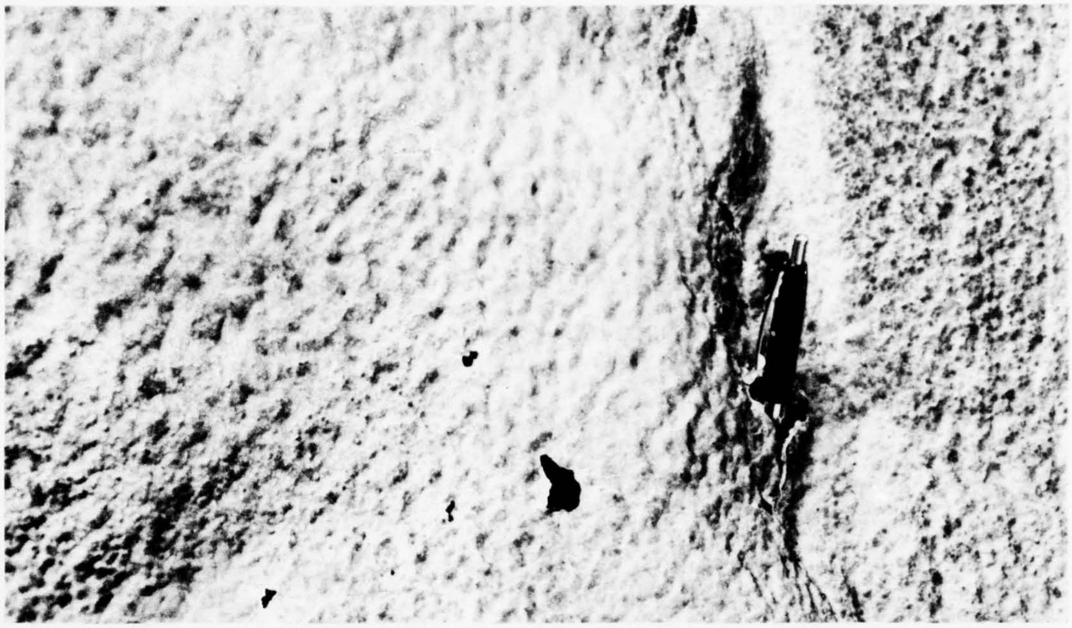
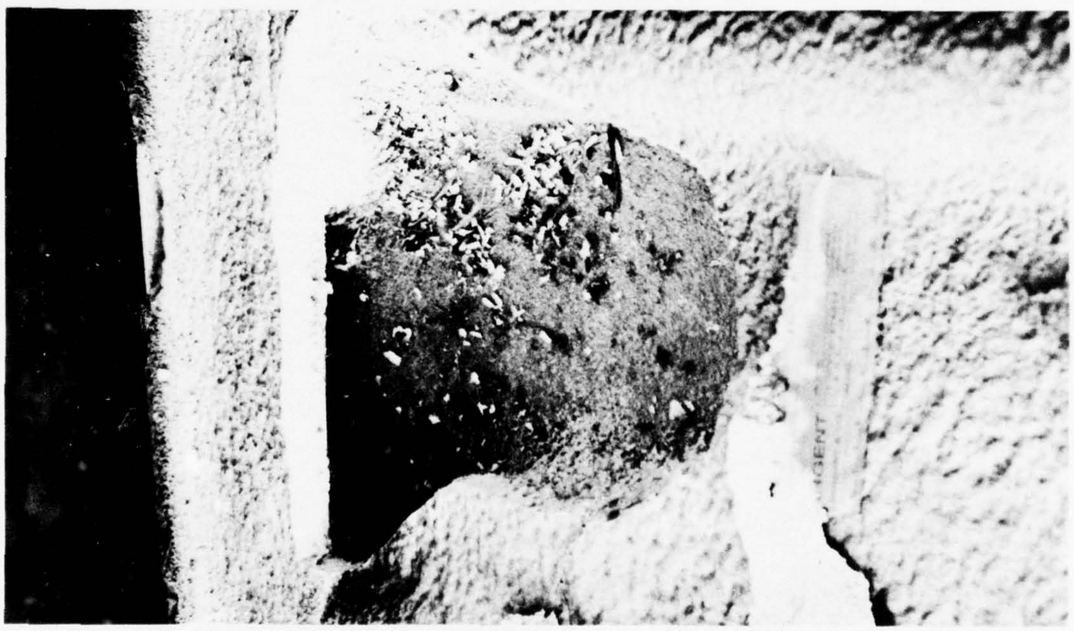


Figure 29. Two Cleaned Spots in System 2 Coating That Show Extent of Dirt Retention by Moisture-Curing Silicone Rubber Coating

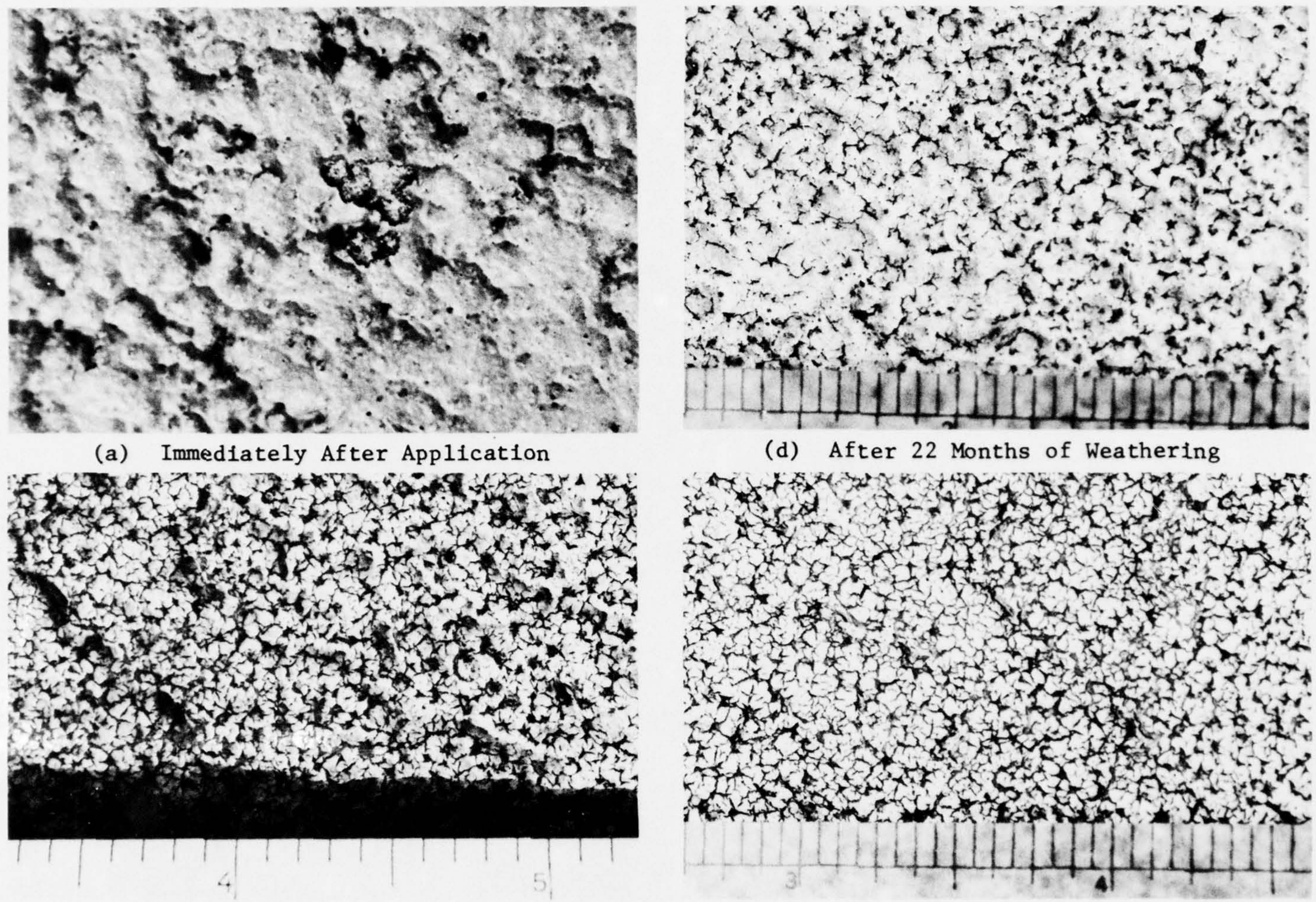


(a) Small Holes in Coating (Note Pen Protruding From Coating).



(b) Void Exposed When Coating Was Removed.

Figure 30. Area in System 2 Section Where Birds Pecked Foam From Beneath Gravel Stop



(a) Immediately After Application

(d) After 22 Months of Weathering

(c) After 18 Months of Weathering

(b) After 9 Months of Weathering

Figure 31. Progressive Degradation of Catalyzed Butyl-Hypalon (System 3)

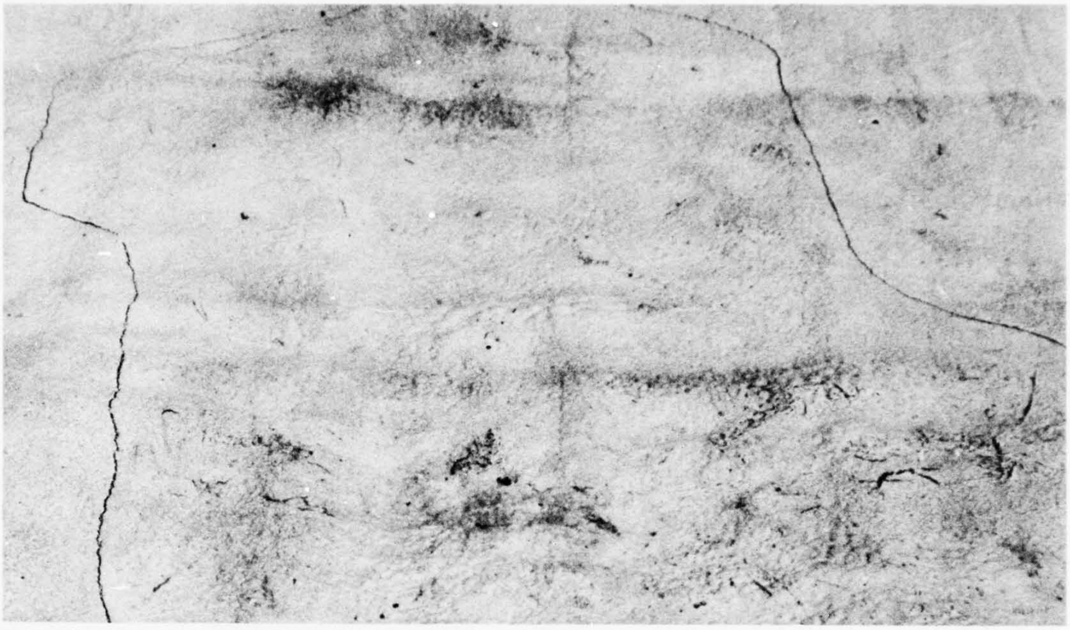


Figure 32. Area of Spongy Foam on North Side of System 3 Section
After 9 Months of Weathering

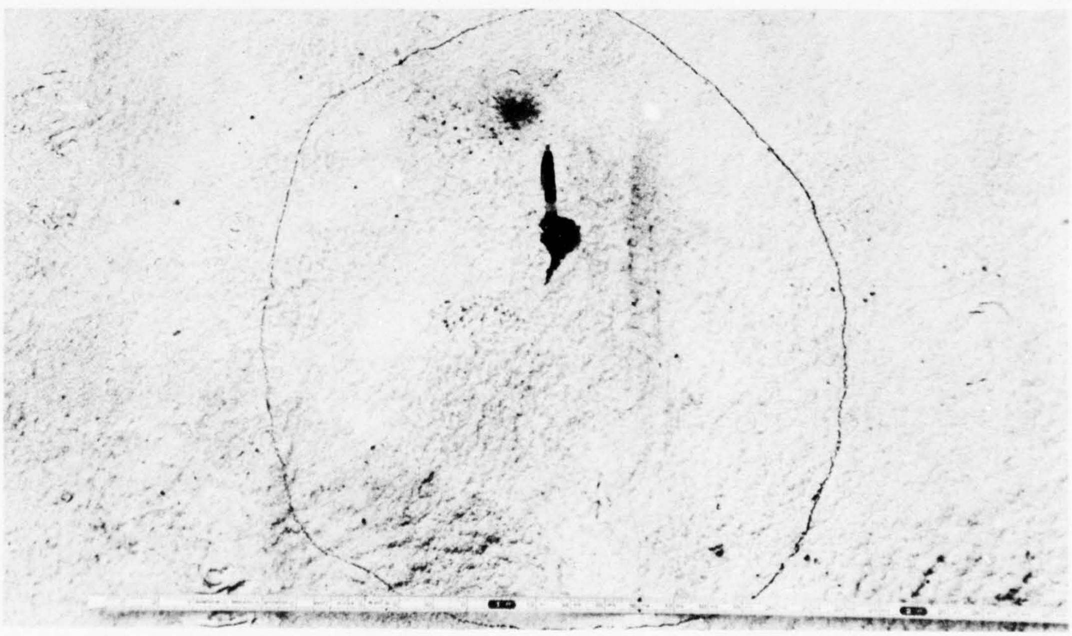


Figure 33. Area of Blistered Foam on North Side of System 3 Section
After 9 Months of Weathering

Figure 34. Overview of South Side of System 3 Section After 18 Months of Weathering

Just before the 22-month inspection, the Clifton area had a severe hailstorm. The hailstones were unofficially described as being as large as golf balls. Interestingly enough, damage was limited to the South Building, Systems 3, 4, and 5; there was no evidence of hailstone damage to the silicone coatings, Systems 1 and 2. Damage in the System 3 section was almost as great as the damage in the System 4 section. Hailstone damage generally results in semicircular to circular breaks in the coating (Figure 35).

This catalyzed butyl-hypalon coating system showed severe deterioration after 22 months of weathering, and it was rated as poor.

System 4. Hypalon Mastic

Hail damage was more severe on this system than on any of the others. Probably the most serious problem with this hypalon mastic other than its susceptibility to hail damage was erosion of the coating from the foam. This was particularly bad on about 200 square feet of the south side of the South Building. Most of this area of severe erosion is shown in Figure 36. Note the difference in color. A close-up of one of the worst portions is presented in Figure 37, in which hail damage can also be seen. It is believed that this severe erosion can be attributed to a combination of insufficient coating thickness and the foam having to remain uncoated overnight. In spite of the apparent "dry" surface the next day, the foam surface may have retained some moisture.

Before this system was coated, a large number of basketball shoe imprints were made in the foam by employees of the contractor. It was found that as the coating has weathered, it has become unable to bridge some of the indentations, and has cracked. This cracking was first observed during the 9-month inspection. Such a heel print is shown in Figure 38; several cracks are visible in the coating.

This coating system also exhibited a minor problem along the edge where it overlapped the System 3 section. The overlap "joint" was poorly constructed, and slight lifting of the foam and coating can be seen in Figure 39.

After 22 months of weathering, this hypalon mastic coating system was rated as poor to fair in performance.

System 5. Catalyzed Butyl-Hypalon

Until the hailstorm mentioned above, this coating system was considered to be performing very well. Damage by hailstones was less on this than on either of the other two systems that were affected. Typical damage is shown in Figure 40. Prior to this storm, weathering of this system consisted of very light flaking in scattered areas of the roof and pinholes in the coatings (Figure 41). These pinholes are characteristic of high-solvent butyl coatings, although in this case, the pinholes have not led to early failure of the system.

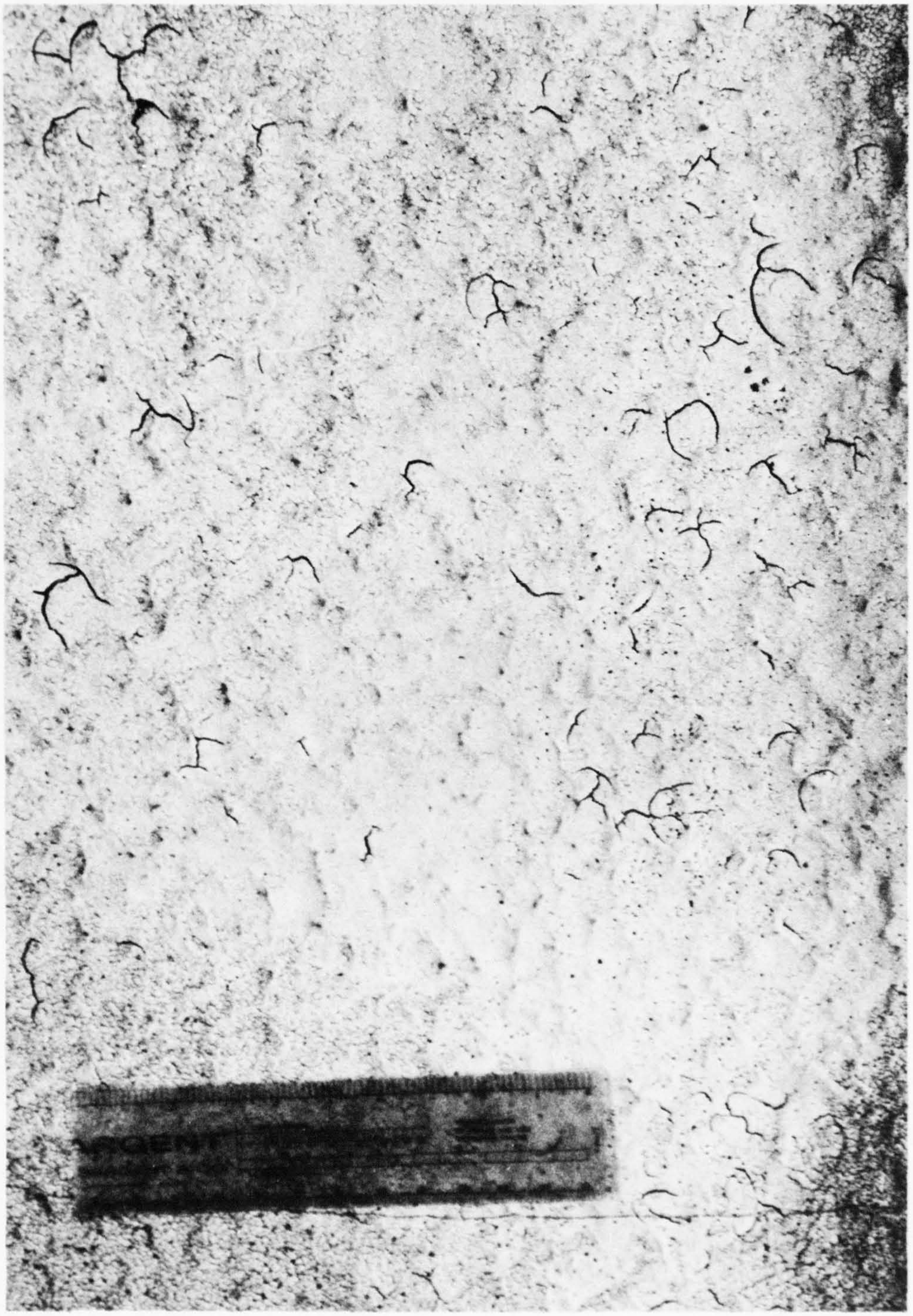


Figure 35. Hail Damage in System 3 Section

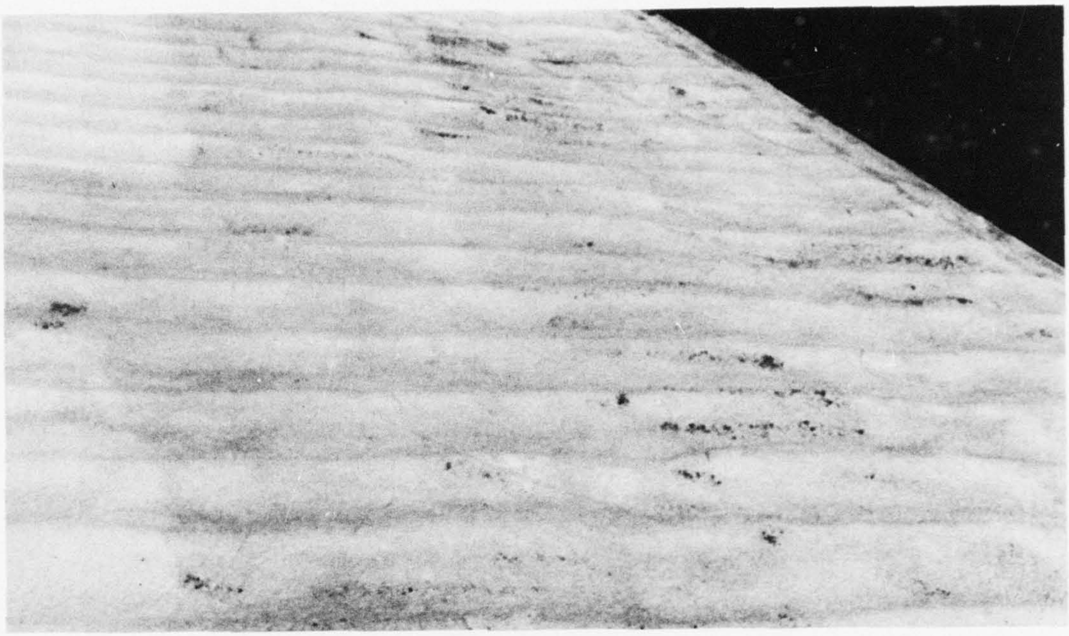


Figure 36. Area of Hypalon Mastic (System 4) Showing Greatest Erosion Damage After 22 Months of Weathering

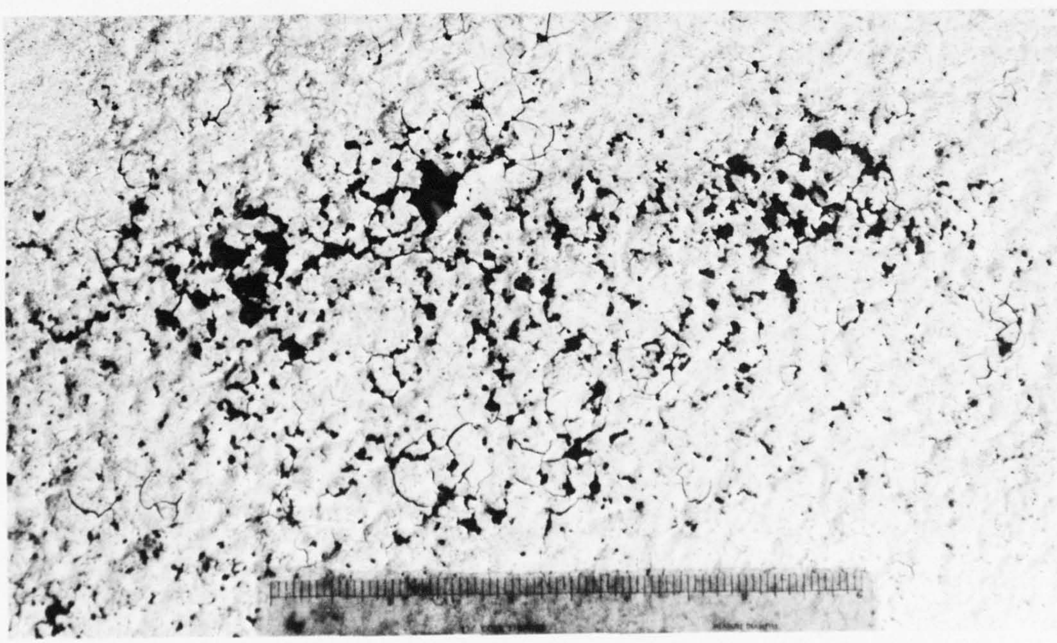


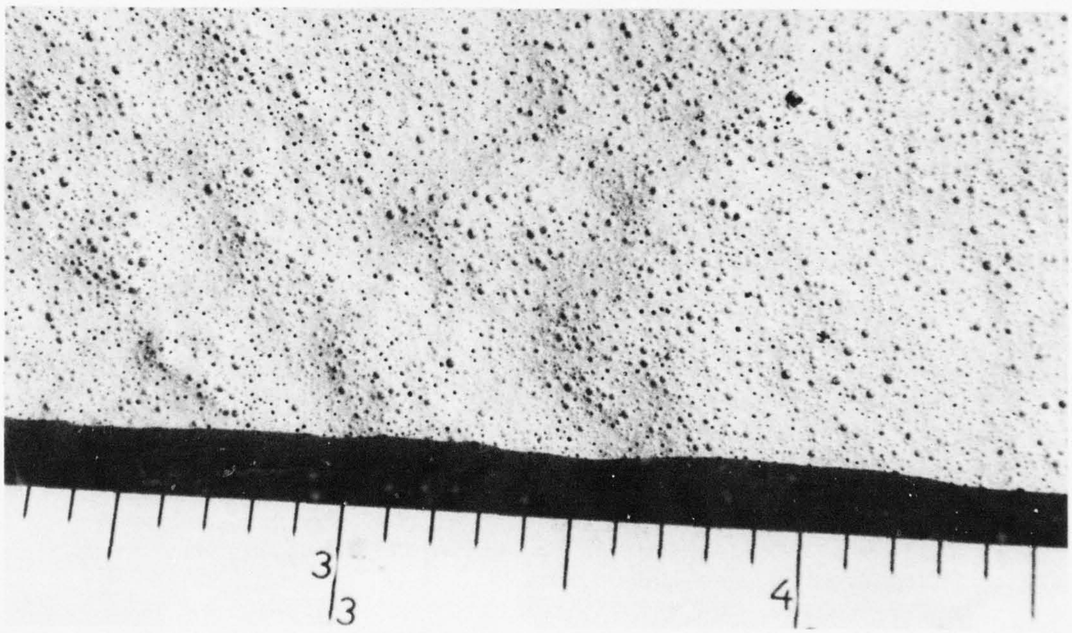
Figure 37. Close-up of Badly Eroded Portion of Hypalon Mastic, (System 4) After 22 Months of Weathering

Figure 38. Cracking of Hypalon Mastic (System 4) in Heelprint After 22 Months of Weathering

Figure 39. Poorly Constructed Overlap Joint Between System 3 Section and System 4 Section

Figure 40. Hailstone Damage to Catalyzed Butyl-Hypalon (System 5) After 22 Months of Weathering

(a) Immediately After Coating



(b) After 18 Months of Weathering

Figure 41. Pinholes in Catalyzed Butyl-Hypalon (System 5)

This system has retained its whiteness about as well as any of the others. After 22 months of weathering, it was rated fair to good for performance.

Vent Flashings

One of the variables in this experimental roof was the manner in which vents were flashed. In some cases, vents were merely foamed and coated; in other cases either the foam or the coating was reinforced with fabric (Figure 42). After 22 months, there was no discernible difference between these flashing methods. All were performing in an excellent fashion.

ROOF REPAIRS

During the 9-month inspection, a number of small spots (1/4 to 1/2 inch in diameter) were found in Sections 1, 2, 4, and 5 in which the coating had flaked off, cracked, or been cut by sliding snow or ice. Since these imperfections were considered to have been mechanical in nature rather than true coating failures, they were patch-coated by CEL personnel on a one-time-only basis to prevent further degradation of the exposed foam. In each section the spot-patching consisted of applying a compatible coating to the spot with a brush. No patch-coating was attempted on the System 3 section, because this catalyzed butyl-hypalon was showing serious deterioration overall.

In August 1974 the foam and coating contractor returned to NRC to repair the areas of poor foam. Progressive removal of the poor foam down to the underlying asphalt primer on the steel deck is pictured in Figure 43. Peripheral edges of the cut foam were then bevelled to provide a better surface for bonding the new foam, as shown in Figure 44. Application of the first lift of new foam is seen in Figure 45. The completed foam portion of the two patched areas in the System 3 section are shown in Figure 46. Repaired areas complete with the catalyzed silicone rubber top coat of System 1 are pictured in Figure 47.

Leaking of water was reported in the vicinity of the junction between the Boiler House and the South Building (see Figure 22). To prevent further leaking, the eave-to-roof connecting areas were filled with foam by the contractor, as shown in Figure 48. These areas were then coated with the top coat of the catalyzed silicone rubber (System 1). No leaking has been reported in the ensuing year since the contractor made these repairs.

Finally, during August 1975, two bird-pecked areas were discovered in the System 2 section, one of which was shown previously in Figure 30. In order to prevent the exposed foam from deteriorating, on-the-spot repairs were made by CEL personnel. The pecked areas were cut out with a sharp knife to expose good foam. The foam was then protected

with a cold asphalt roof patching material (Figure 49). These repairs should provide sufficient protection to the foam. Since the hollowed-out areas are adjacent to the gravel stop, standing water will run underneath the gravel stop and off of the roof.

ENERGY CONSERVATION

One of the purposes of this experimental roofing installation was to determine the savings in fuel consumption afforded by the urethane foam insulation. With a nominal thickness of 2 inches, the calculated value of the foam is 0.06 Btu/(hr) (ft^2) (°F). This value is close to the U value of 0.05 stipulated in the October 1972 issue of the Department of Defense Construction Criteria Manual.

Since only one or two rooms of the Reserve Center are air-conditioned during hot weather, meaningful comparisons of fuel consumption before and after application of the foam are limited to usages of natural gas for heating in the colder seasons of the year. The requirement for heating can be expressed in terms of the number of degrees that the average daily temperature falls below 65°F; i.e., it is assumed that heat is required whenever the temperature is less than 65°F. For example, if on a given day the average temperature is 40°F, the degree calculation is 65 minus 40 or 25. Since the time period is one day, this is commonly expressed as "25 degree-days." It is often convenient to compare these figures on a monthly basis, so the sum of the degree-days for each day of a given month is the "monthly degree-days." Because the concern here is natural gas consumption for heating, the figures used are called "heating monthly degree-days." The higher the number of heating monthly degree-days, the more severe the weather.

Table 6 shows the heating monthly degree-days for 2 years before and 2 years after installation of the foam. The average values shown on the bottom line of Table 6 reveal that the weather was slightly more severe in the 2 years after foaming than it was in the 2 years before foaming - 4,603 degree-days compared with 4,572 degree-days.

Table 7 lists the natural gas consumption in cubic feet on a monthly basis. The second and third columns show the monthly gas usage prior to foam installation; the last two columns show gas usage since foam installation. On the next-to-last line is a summation of the gas consumption for the period of October through May for each year. There has been a rather dramatic reduction in gas usage since the roofs were foamed. In the last line of Table 7, the October through May totals are averaged for 2 years before and 2 years after foaming. This reduction in gas usage as indicated in the last line is 53%. Figure 50 also depicts rather impressively the decrease in consumption of heating gas since the roofs were foamed (October 1973).

Figure 42. Fabric-reinforced Vent Flashing in System 2 Section, Performing Well After 18 Months of Weathering

Figure 43. Removal of Poor Foam in System 3 Section

Figure 44. Bevelling of Foam in System 3 Section

Figure 45. Application of New Foam in System 3 Section

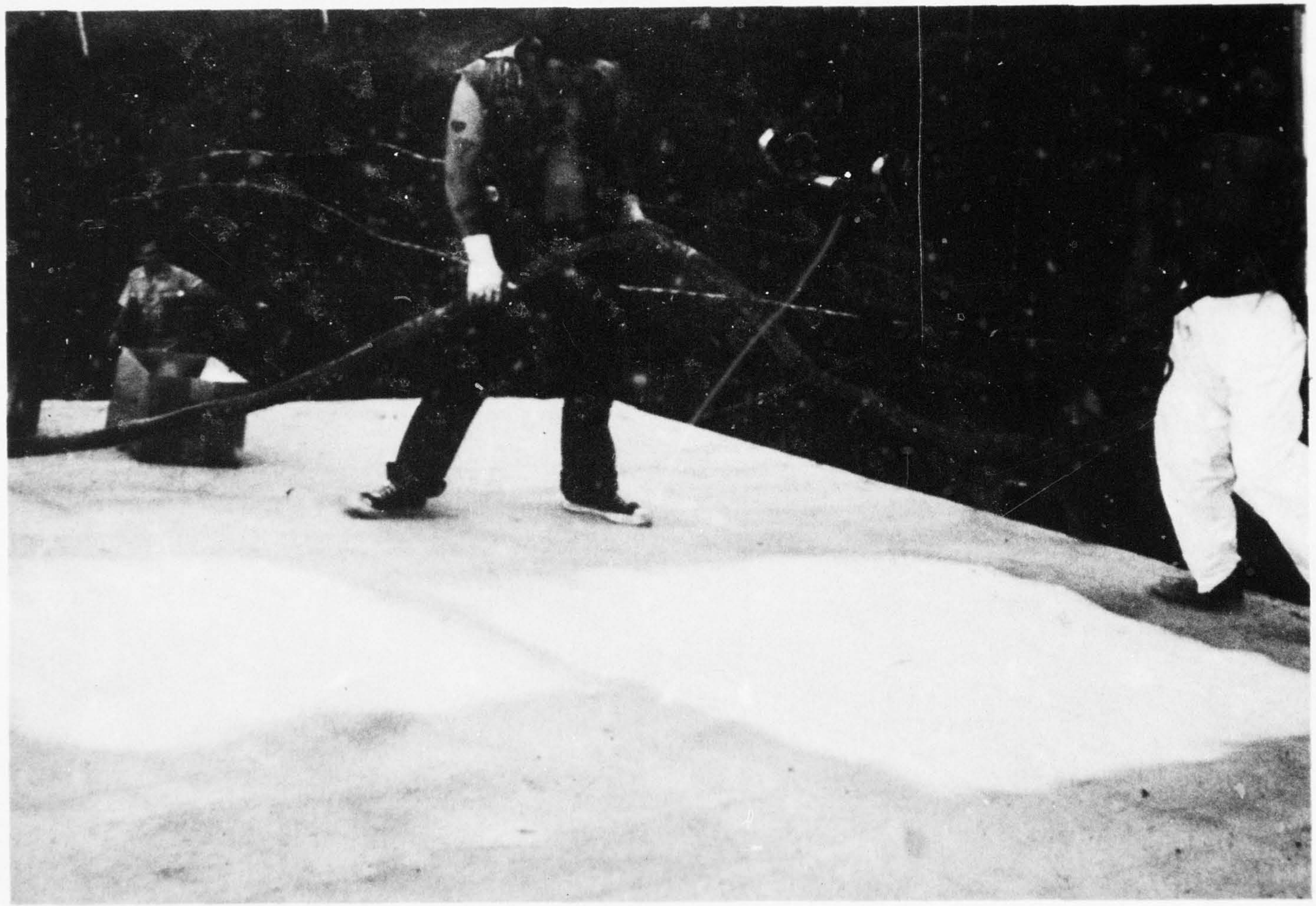


Figure 46. Completed Foam Portion of Patches in System 3 Section

Figure 47. Repaired Areas Complete With Catalyzed Silicone Rubber Top Coat of System 1

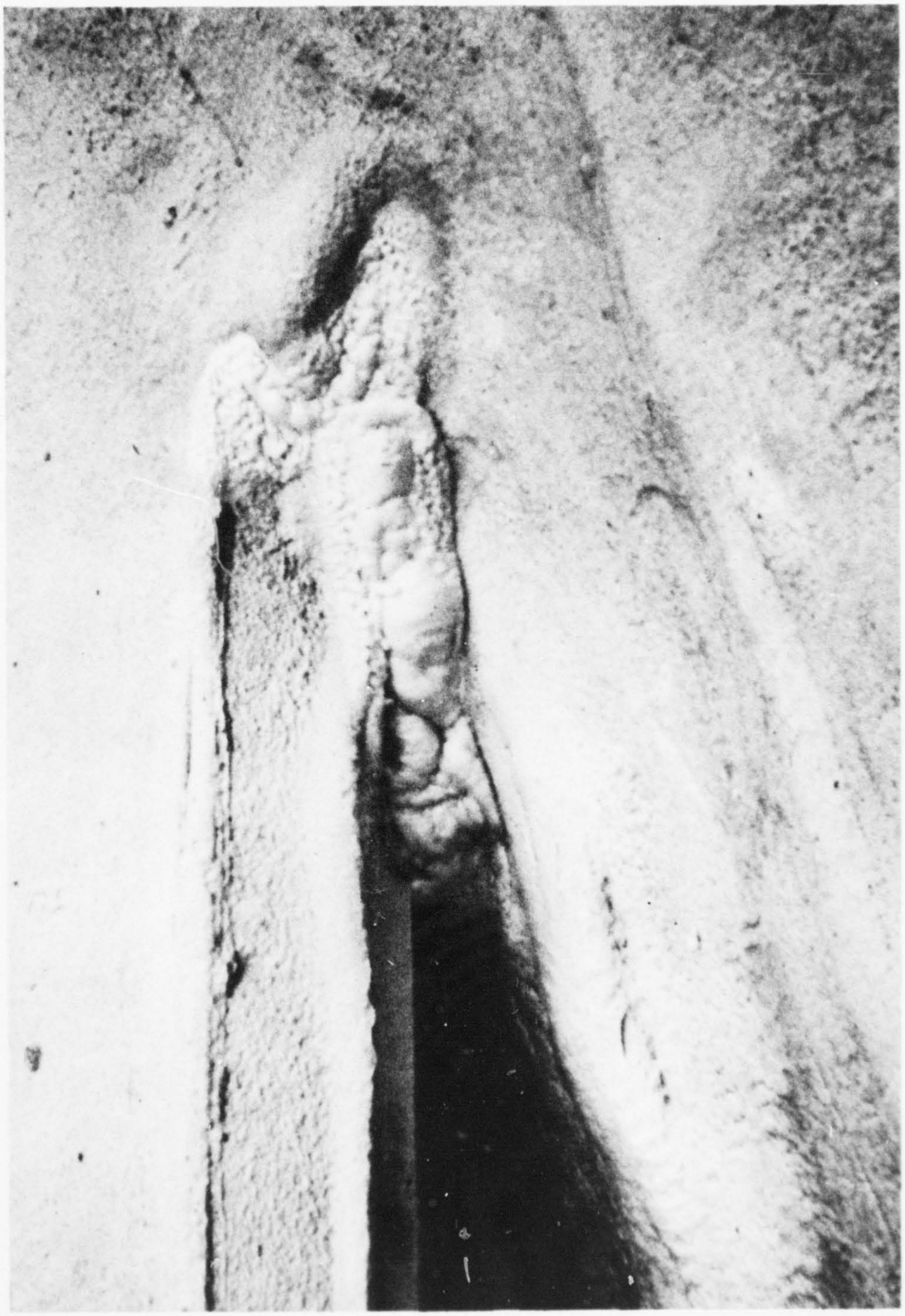


Figure 48. Junction of Boiler House Eave and South Building Filled With Foam

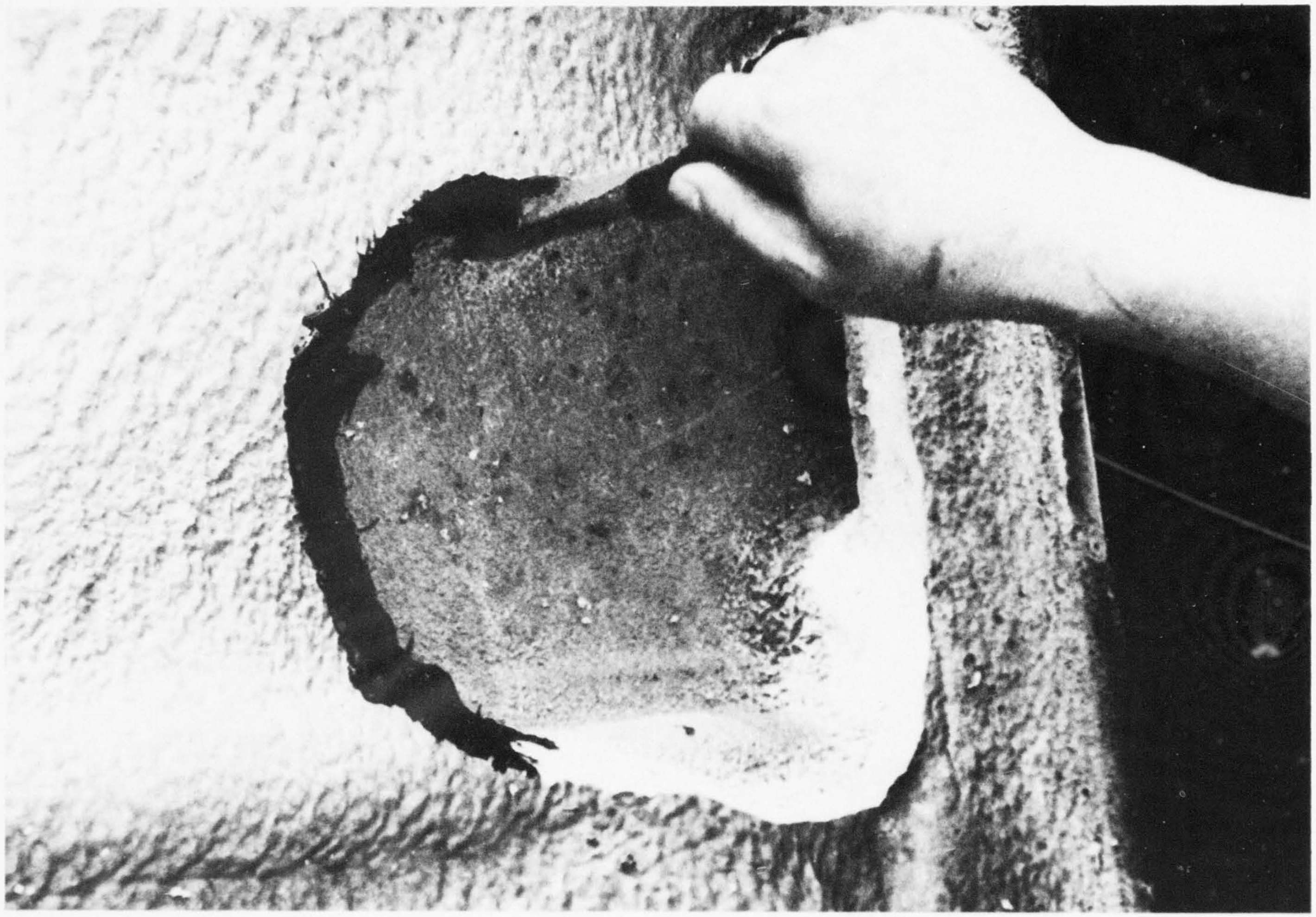


Figure 49. Repair of Large Bird-Pecked Area in System 2 Section

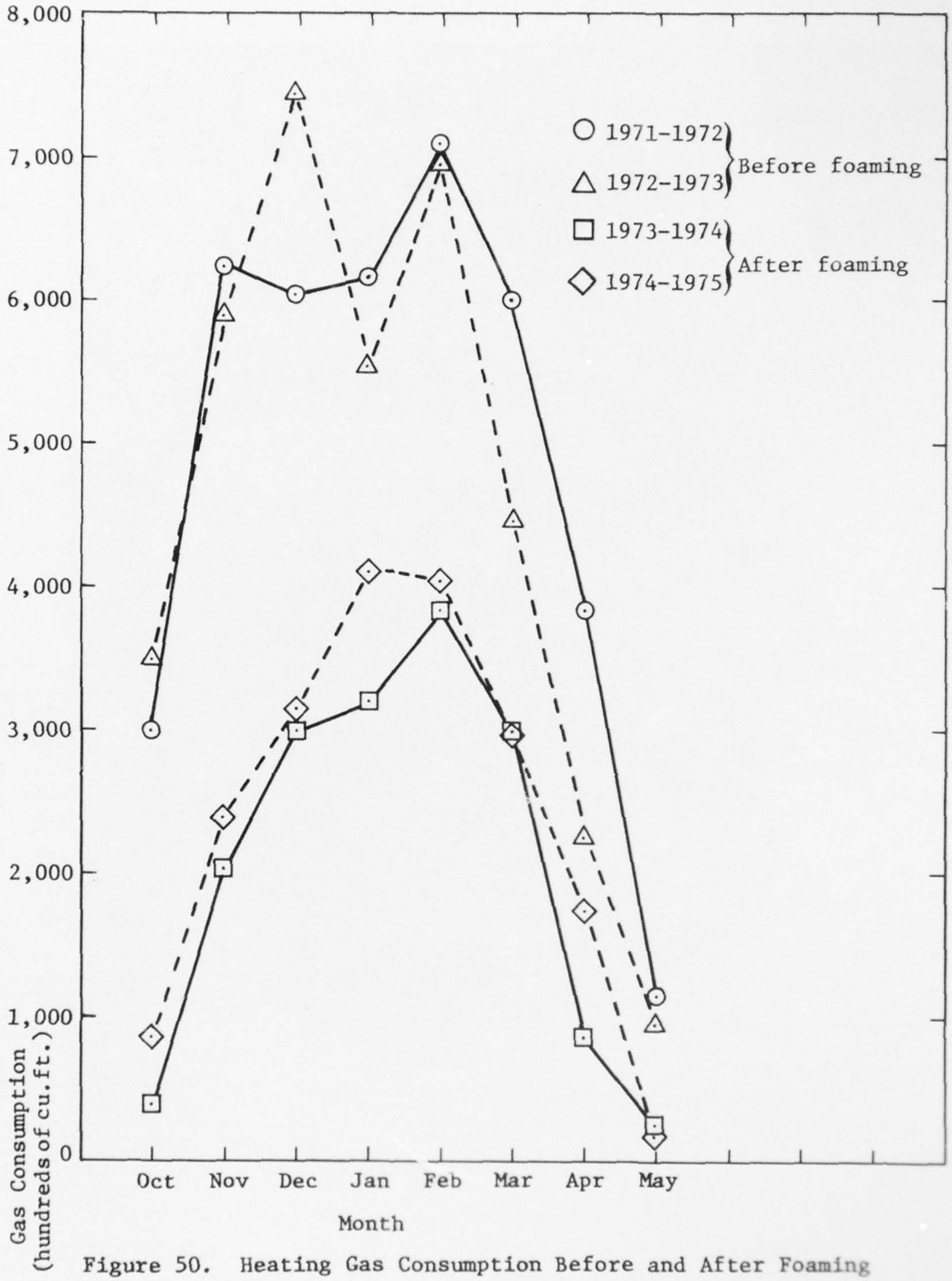
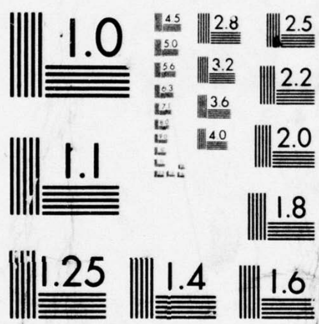


Figure 50. Heating Gas Consumption Before and After Foaming

AD-A031 046 CIVIL ENGINEERING LAB (NAVY) PORT HUENEME CALIF F/G 13/13
EXPERIMENTAL POLYURETHANE FOAM ROOFING SYSTEMS.(U)
AUG 76 J R KEETON, R L ALUMBAUGH, E F HUMM
UNCLASSIFIED CEL-TN-1450 NL

2 OF 2
AD
A031046

END
DATE
FILMED
11-76



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Table 6. Heating Monthly Degree-Days for the Clifton, New Jersey Area[a]

Month	Heating Monthly Degree-Days[b]			
	Prior to Foam Installation		After Foam Installation	
	1971-1972	1972-1973	1973-1974	1974-1975
October	95	356	166	341
November	569	599	479	521
December	724	776	787	802
January	909	906	909	864
February	969	882	921	832
March	757	504	661	775
April	444	339	273	524
May	93	163	127	84
June	19	1	12	6
July	0	0	0	0
August	0	0	0	1
September	22	18	62	59
Total	4,601	4,544	4,397	4,809
Average	4,572		4,603	

a) Data obtained from monthly National Oceanic and Atmospheric Administration publication, "Climatological Data." Weather station is located at Newark, New Jersey.

b) Heating monthly degree-days are the sum of the negative degree-departures of average daily temperatures from 65°F (see text).

Table 7. Monthly Gas Consumption

Month	Monthly Gas Consumption (cu ft)			
	Prior to Foam Installation		After Foam Installation	
	1971-1972	1972-1973	1973-1974	1974-1975
October	298,200	348,200	39,200	85,000
November	622,200	588,000	201,000	238,600
December	601,200	744,400	297,600	313,600
January	612,400	553,000	317,000	408,000
February	708,600	692,800	380,400	402,400
March	598,200	445,000	296,200	294,600
April	380,000	232,200	84,000	172,200
May	110,600	91,600	21,800	16,000
June	24,200	7,200	6,800	3,600
July	7,000	6,400	6,000	
August	6,200	5,400	7,800	
September	47,600	7,400	7,200	
Monthly Average October-May	491,425	460,775	204,650	241,300
2-year monthly Average	476,100		222,975	

FLAMMABILITY AND FIRE SAFETY

Susceptibility to damage by fire is always a potential problem with plastic materials, and urethane foam systems are no exception. Earlier it was mentioned that PUF roofs should meet the same fire requirements as any other roofing system. That is, the coated urethane foam roofing systems tested as a system should have a flamespread of 25 or less and should have a UL790 Class A, B, or C rating. The fact that the urethane foam or the coating system alone has such a rating is not sufficient; the total system must have a UL790 classification. If the proper fire safety rated materials are not used or if fire safety rated materials are used improperly, they could constitute a serious fire hazard. Fire safety criteria for the use of urethane foams in roofs are contained in paragraph 4 of NAVFACINST 11320.2, "Fire Protection Criteria for Cellular (Foam) Plastics in Construction," dated 15 March 1974. Commensurate with this, coated polyurethane foam roofing systems selected for this experiment had either a UL790 Class A or B rating.

In recent correspondence with CEL, NAVFAC expressed strong concern that urethane foam roof systems applied directly to metal roof decks might constitute a serious hazard in the case of a fire originating inside the building, i.e., a PUF roofing applied directly to the exterior of a metal roof deck might contribute fuel and/or smoke to a fire originating inside the building. CEL concurs that this is a potential problem. Since this type of roof deck construction has not been evaluated for this purpose by either Underwriter's Laboratories (UL) or by Factory Mutual (FM), CEL has suggested to NAVFAC that such tests be conducted by both laboratories to clarify the issue. Until these tests are conducted, CEL is not recommending the use of urethane foam roofing systems applied directly to metal roof decks.

DISCUSSION

Aside from the fact that the roofs of the buildings at the Reserve Center have not leaked since application of the sprayed-on PUF roofing systems, the most significant contribution has been the reduction in the amount of fuel consumed. The average monthly gas consumption for the months that require heating (October through May) for the 2 years prior to application of the PUF roof system was 476,100 cubic feet (see Table 7). This same monthly average for the 2 years following application of the new roofing system was 222,975 cubic feet. This is a reduction of about 53% in fuel usage, a figure that is truly impressive in these days of energy shortages and drastic increase in the price of fuel.

While a few problems did occur during the application of the five experimental PUF roofing systems, none were insurmountable. With very few exceptions, all materials were applied as specified by the contract and according to manufacturers' instructions. One of the few variances from the contract specification was that all of the old coating was not

sandblasted from the metal roof prior to application of the PUF. The loose coatings were instead scraped from the metal, and the bare areas were spot-primed with the same asphalt coating that was used all over the roof. After almost 2 years of weathering, no evidence has been found that the foam has lost adhesion to the roof deck. Spray-applied PUF generally exhibits excellent adhesion to most substrates. Thus, in many cases, a primer may not be required; whether or not a primer is required should be determined on an individual basis. A primer does provide additional insurance that the foam will adhere satisfactorily to the roof deck. There are chlorinated rubber primers available commercially that have proven satisfactory for this purpose. The use of a chlorinated rubber primer instead of the asphalt primer should eliminate any potential fire problems that might be associated with the use of an asphalt primer. If an asphalt primer, such as SS-A-701a is used, sufficient drying time should be allowed (2 to 3 weeks) to permit the solvent to evaporate before the foam is applied, so that adhesion of the foam is not adversely affected.

No major problems were experienced in the spray-application of the foam. Sponginess of the foam was observed in a few small areas, and one small blister was found; these were all caused by improper proportioning of the foam components. These small areas were repaired easily by the contractor. Even the areas in which the foam surface was rougher than desired have performed well because they were properly coated.

Some major problems were experienced in the spray-application of two of the coatings -- the catalyzed butyl-hypalon of System 3, and the hypalon mastic of System 4. The application of the catalyzed butyl base coat of System 3 was interrupted many times by blockage of the spray gun -- a gun specially designed to spray this particular material. Each blockage required disassembly of the gun for a complete cleaning, a very time-consuming operation. Applying this base coat at the prescribed rate caused the material to run down the roof. As a result, the rate had to be reduced from that recommended by the manufacturer. This same running problem was encountered with the catalyzed hypalon top coat of System 3 when applied as directed by the manufacturer. There were very few blockage problems with the hypalon top coat, but it had very poor hiding characteristics, and the finished system had a very blotchy appearance. The lack of proper thickness and hiding ability was probably largely responsible for the very rapid degradation of this system through checking, cracking, and erosion of the top coat. This System 3 section needed to be recoated with a suitable elastomeric material even before the hailstorm-caused damage.

Spray-application of the hypalon mastic of System 4 was also very difficult because of the thixotropic nature of the material. Raising the temperature of the material to 125°F did not eliminate the problem. It was necessary to "purge" thickened portions of the material from the gun frequently. Although the material was extremely thixotropic, the solids content was only about 30%. It was thus necessary to apply a

minimum wet film thickness of 90 mils to obtain a minimum dry film thickness of 30 mils. Such a heavy wet film thickness is difficult to obtain without a certain degree of irregularity. The purging of the spray gun together with the heavy wet film thickness requirement slowed application of this system to the point where it was not possible to coat the entire area of System 4 the same day that the foam was applied. Foam was left unprotected overnight on about one-third of the area, which may have contributed to the excessive erosion of this system on the south side of the section. However, it does not appear to have been a major factor because the heaviest erosion is occurring within a small, 200-square-foot area at the bottom of the roof rather than over the entire south side of the section. The fact that this small area shows a color different from the rest of System 4 suggests that either the coating was applied too thinly in this area or that the composition of the coating had changed. This latter possibility seems somewhat unlikely, because no obvious color change was noted immediately after the coating was applied; the color change was not noticed until the 9-month inspection.

When the shoe imprints and resultant cracking in the hypalon mastic coating of System 4 were first noticed at the 9-month inspection, it was assumed that they had occurred after the system had been applied. However, a study of photographs taken after foaming but before coating revealed that the footprint indentations were present and, therefore, must have been made by contractor personnel during foaming. They were not observed immediately following application of the coating because the thixotropic nature of the hypalon mastic hid them from view at the time. As the coating cures, however, it shrinks and is unable to bridge the indentations without cracking. After the 18-month inspection, it was decided that the erosion and cracking of the hypalon mastic of System 4 were of sufficient magnitude to indicate the need for recoating within the next year. The additional damage caused by hailstones during the 1975 summer storm necessitates recoating all of System 4 as soon as possible to prevent degradation of the foam.

Although it was necessary occasionally to purge the spray gun while applying the catalyzed butyl base coat of System 5, it did not constitute a real problem. Application of both the butyl base coat and hypalon top coat proceeded fairly smoothly. This system was also performing very well with very little evidence of coating deterioration through the first 18 months.

Just prior to the 22-month inspection, the roofs were subjected to the hailstorm that damaged the coatings of Systems 3, 4 and 5. While the hail damage to System 5 was less than to either of the other two, this area also requires recoating as soon as possible to prevent excessive deterioration of the foam. Hail damage on all three systems was more severe on the northerly and/or easterly surfaces than on southerly and/or westerly surfaces, presumably indicating the storm was moving from the northeast to the southwest.

No evidence of any hail damage could be found on the North Building that was coated with the two silicone rubber coatings, Systems

1 and 2. This building is at a higher elevation than the South Building and presumably would have been hit first by the hailstones because of the direction in which the storm was moving. Damage caused by falling hailstones would appear to be dynamic in nature, in which case the tensile strength may well be the controlling factor. As noted in Table 8, tensile strengths for the silicone rubber coatings, Systems 1 and 2, are above 300 psi, while this property for the two butyl-hypalons (Systems 3 and 5) and hypalon mastic (System 4) is below 300 psi. The elongation, on the other hand, shows higher values for Systems 3 and 4 than for Systems 1, 2, and 5. It would appear then, that in terms of hailstone resistance, the tensile strength of the protective coating films is more important than the elongation and that such a coating film must have a tensile strength above 300 psi in order to withstand damage from hailstones of the size that hit the Clifton, New Jersey, area in the summer of 1975.

The application of both of the silicone rubber coatings was very smooth even though the catalyzed silicone rubber of System 1 required a specially designed piece of spray equipment. The moisture-cured silicone rubber of System 2 was especially easy to apply as it was a one-package material. The silicone materials also performed very well for the entire 22-month exposure period. Results to date indicate that use of the mineral granules in the wet top coat is well worth the additional 3 to 10 cents per square foot that this might add to the price. The granules provide added protection to the coating system against the weather, furnish a walking surface which is fairly resistant to damage by foot traffic, and inhibit potential bird-pecking where this is likely to be a problem.

The granules do increase the heat absorption by the roof system, at least in the gray color used in the experiment. In bright sunshine immediately after application, the roof section having gray silicone with granules was about 20°F warmer than the roof section having the same silicone without granules (both in System 1). After almost 2 years of weathering, the section having gray silicone with granules is about 3° to 5°F warmer than that part of the System 1 section without granules. This reduction in temperature differences (top of foam) after weathering is probably due to the excessive dirt retention of the silicones and is even more obvious when comparing top-of-foam temperatures of the gray and white silicones. Immediately after application, the top-of-foam temperature of the white silicone of System 2 was about 30°F lower than that of the gray System 1 (without granules) during the warmest part of the day. After 2 years of weathering, the same temperature difference is only 8° to 10°F. This is believed to be due primarily to the dirt retention on the white silicone coating which gives this system a dirty gray color. Even after weathering for 2 years, the two systems that retained their white color fairly well, Systems 4 and 5, show a lower temperature than the gray silicone of System 1 by some 30° to 40°F. These cooler temperatures under the whiter coatings can be significant when air-conditioning costs are a consideration. When mineral granules are used, they should be white in color.

Table 8. Tensile Properties of Free Films of Coating Systems

System Number and Description	Average Tensile Properties[a]	
	Tensile Strength (psi)	Elongation (percent)
1. Catalyzed silicone rubber	311	97
2. Moisture-curing silicone rubber	389	204
3. Catalyzed butyl-hypalon	117	308
4. Hypalon mastic	227	489
5. Catalyzed butyl-hypalon	142	79

[a] Tensile properties were determined on free films prepared at CEL by spray-applying each total coating system, according to manufacturer's directions, to glass plates previously treated with a release agent. After aging in the laboratory for 6 months, the films were stripped, cut to proper size and then placed in a controlled temperature and humidity room for at least 7 days to equilibrate. The specimens were then measured, and the tensile properties determined essentially in accordance with a testing procedure developed at CEL and reported in Technical Report R-827: Coating research: Tensile testing procedure and its application, by E. S. Matsui, Port Hueneme, CA, Nov 1975.

As noted earlier, poor quality foam areas can be very easily repaired. The poor quality foam is removed to the roof deck, the edges of remaining foam are beveled, and the area is refoamed and coated. In addition to repairing the foam, the touch-up of protective coatings can also be easily accomplished. CEL believes that any roofing contract should require the contractor to replace and coat any bad or unbonded foam for a period of at least one year after construction.

It was mentioned earlier that small spots or cracks in the coatings were spot-patched on a one-time-only basis after the coatings had weathered for about 9 months. It took only about 2 hours to spot-patch the entire roof area, about 160 squares. CEL believes that the service life of any urethane foam roof system can be extended significantly if such spot-patching is conducted on at least an annual basis. On the basis of experience at the Reserve Center, the cost for such a maintenance procedure would be minimal and, if the foam were prevented from deteriorating by such a procedure, the time between complete recoating of the foam roof system might be extended significantly.

Cost is always a very significant factor when choosing a roofing system to use for a given structure. When urethane foam roofing systems are compared to other roofing systems (usually a BUR system of some sort), both cost and performance are important factors. While Systems 3, 4, and 5 have suffered damage by hailstones that require their recoating in the near-to-immediate future, the two silicone coatings, Systems 1 and 2, have been performing very well. It is believed that after almost 2 years of weathering, these systems are performing at least as well as a built-up roof would be performing. The cost of such a system would be expected to vary depending on labor and material costs at the construction site. However, based on current prices, CEL estimates that either System 1 or System 2 can be obtained by contract at a cost of $1.00 to $1.50 per square foot. When comparing costs between a PUF roofing system and an insulated BUR, care must be taken to assure that relative insulation efficiencies are also considered.

Any properly selected roofing system will perform its intended function and have a long service life if (1) specified materials are obtained, (2) materials are in proper condition when applied, and (3) materials are applied properly. Failure to meet any one of these three requirements, of course, accounts for most, if not all, of the roofing problems encountered in the industry today. Construction inadequacies occur with any system, so it is no more realistic to say that the requirement of a skilled operator for the foam is a "disadvantage" than it is to say that the requirement for the asphalt used in a BUR must have a certain temperature or viscosity is a "disadvantage." Most successful roofing systems have more advantages than disadvantages for a given use or none of them would be used. CEL believes, likewise, that spray-applied PUF roofing systems have more advantages than disadvantages when they are logically and scientifically considered as a candidate system for a given roof. As with most roofing systems, spray-applied PUF is not suited for certain roof deck applications and, therefore, should not be selected as

a candidate system. For example, CEL is reluctant to recommend a PUF system for a flat roof deck of any type due to the potential damage standing water might cause to the coating or foam. For the type of sloped metal roof deck involved in this experimental study, it is highly doubtful if any other system could have sealed the leaks, provided adequate insulation, and waterproofed the insulation in as few construction operations as did the spray-applied PUF.

FINDINGS AND CONCLUSIONS

The following findings and conclusions are presented on the basis of results of up to 22 months of weathering of the five different PUF roofing systems at NRC, Clifton, New Jersey:

1. A PUF roof system can be expected to reduce fuel usage by as much as 53% compared to metal roofs with little or no insulation.
2. White coatings can reduce daytime temperatures on the top surface of roof systems by 10° to 30°F compared to medium gray coatings.
3. Gravel stops should not be used on roofs of metal buildings that are to have PUF roof systems, because their use causes low places where water can pond.
4. Butyl-hypalon and hypalon mastic coating systems (Systems 3, 4, and 5) were damaged by hailstones. Such damage requires that PUF roof systems coated with these systems be recoated with hail-resistant coatings as soon as possible in order to prevent degradation of the PUF systems.
5. Roof sections coated with silicone elastomers were not damaged by hail. It appears that an elastomeric coating system for use on PUF should have a minimum tensile strength of 300 psi to exhibit resistance to hail.
6. The urethane foam, the silicone elastomeric coating (Systems 1 and 2), and a catalyzed butyl-hypalon (System 5) were all easily applied. One of the catalyzed butyl-hypalons (System 3) and the hypalon mastic (System 4) were difficult to apply. Systems 1, 2, and 5 performed very well and were comparable until System 5 was damaged during a hailstorm.
7. Application of roofing granules in the wet top coat appears to improve performance characteristics of the coating systems and makes the PUF system more resistant to bird-pecking.
8. Localized failures in polyurethane foam roofing systems are easily repaired, restoring original integrity of the roofing system.
9. The excellent insulating characteristic of the PUF is indicated by the stabilization of the base of foam and attic temperatures at about 70° ± 10°F year round.
10. Failure to remove all old coatings from the roof deck prior to foaming has not resulted in disbonding of the foam.

RECOMMENDATIONS

1. During construction of a spray-applied PUF roofing system, no more foam should be applied in any one day than can be coated in that same day.
2. When vapor-permeable coatings are specified for PUF, the silicones of Systems 1 and 2 are recommended. When vapor-impermeable coatings are required, the catalyzed butyl-hypalon of System 5 is recommended if hailstones are not likely to be a problem.
3. For hail resistance, a protective coating for the PUF should have a minimum tensile strength of 300 psi. Silicone rubber coatings are recommended for moderate hail resistance.
4. The protective coatings over PUF should be white or, with gray coatings such as the catalyzed silicone rubber of System 1, white granules should be used in the top coat.
5. Granules should be placed in the top coat of protective coatings to provide mechanical protection of the coating system and to reduce or eliminate bird-pecking.
6. A minimum thickness of 2-1/2 inches of PUF is recommended to stabilize interior temperatures and to meet DOD criterion for energy conservation on roofs with no existing insulation.
7. As soon as possible, the South Building should be top-coated with a compatible elastomeric coating, preferably a silicone or a urethane. White granules should be used in the top coat.
8. Gravel stops should not be used on the eaves of metal buildings that are to have spray-applied PUF roofing systems.
9. To avoid contractor deviation from the specifications, an inspector knowledgeable in the field of PUF roofing should be present at all times during construction of PUF roofing systems.
10. More experimental roofing installations of the type reported herein should be made on Navy structures in different climatic regions to provide life-cycle evaluation and energy conservation capabilities of spray-applied PUF roofing systems. Similar experimental installations of other new roofing systems should also be made as opportunities present themselves.
11. PUF roofing systems should have a UL790 rating for top-of-roof fires. PUF roofing systems should not be spray-applied directly to a metal deck until the safety of this type of construction exposed to a fire originating inside a building can be verified by UL and/or FM.

ACKNOWLEDGMENTS

Many persons have contributed to the success of this experimental roof study. The authors particularly wish to express appreciation to R. W. Buchman, LCDR, USNR, Commanding Officer; SK1 David E. Fox USN (TAR); YNC R. S. Pierce; SK2 R. F. Laughlin, and other personnel of the Naval Reserve Center, Clifton, New Jersey, for their assistance during roof construction and for making daily temperature measurements. Appreciation is also expressed to Mr. Theodore Estberg, Architectural Branch, NORDIVNAVFAC for preparing the contract specification and to Mr. Carl Sieger, Inspector, ROICC, NAVFAC contracts, New York area, for his cooperation during roof construction.

The authors also wish to thank CEL Materials Engineering Technician V. Hernandez for installation of additional thermocouples as well as for conducting one of the periodic inspections. They also express thanks to CEL Physical Science Technician T. R. Tree for conducting tensile tests on coatings and tests on foam.

Appendix A

TEST AND EVALUATION PROGRAM FOR
POLYURETHANE FOAM ROOFING SYSTEMS
AT
NAVAL RESERVE CENTER,
CLIFTON, NEW JERSEY
AUGUST, 1973

OBJECTIVE: To study the long-term performance of roof sections of spray-applied polyurethane foam protected by five different coatings. The foam and coating systems are placed over a metal ribbed roof.

APPROACH: To properly evaluate the different foam roofing systems on a comparative basis, the systems must be installed in accordance with the latest state-of-the-art using proper techniques and specifications and following recommendations by manufacturers of the products involved. Five different coating systems will be applied over the same brand of spray-on urethane foam to obtain watertightness and insulation of the roofs at the Naval Reserve Center, Clifton, New Jersey. The foam and protective coatings to be used are specified in the contract specification. Requirements for preparation of the existing roof surface, for proper foam installation, and for applications of the coatings have also been detailed in the contract specification and this specification is considered a part of this test and evaluation program.

Polyurethane foam provides excellent insulation as long as it remains dry and/or does not degrade from exposure to ultraviolet rays of the sun. To prevent ultraviolet degradation and to waterproof the surface, foam should be protected the same day it is applied with coatings developed specifically for this purpose. Since these coatings are often of different generic types, they differ in performance and in their ability to provide long-term protection to the foam. It is one of the purposes of this study to determine the relative efficiency with which five different coating systems will protect a properly applied polyurethane foam surface over a period of several years.

As stated earlier, the foam loses its insulating ability as it becomes wet or degrades. Changes in insulating ability should be detectable by making temperature measurements at the base of the foam, i.e., at the foam-metal interface. In addition, the ability of the protective coating to reflect the sun's rays should be detectable by measuring the temperature at the top surface of the foam, i.e., at the base of the coating. The overall insulating efficiency of the foam should be detectable by comparing the outside air temperature with the temperature at the base of the foam, with due consideration given to the air temperature immediately below the roof (inside the building).

CONSTRUCTION PHASE: CEL/NORDIVNAVFAC personnel will monitor and accurately record in writing and with photographs each step of the construction, including the following items:

1. Ascertain the condition of the existing roof surface before and after sandblasting.

2. Monitor application of the asphalt sealer to the clean, dry roof surface. A sample of the sealer will be analyzed at CEL for conformance with specification.

3. Monitor application of the foam, including measurement of finished thickness. Samples of the foam as applied and of the foam components will be taken to CEL, the latter for preparation of foam specimens under controlled conditions. Comparative tests will be made to determine density, compressive strength, and tensile strength.

4. Monitor application of the coatings, both base and top coats, including measurement of wet film thickness to assure the desired dry film thickness. Samples of each of the coating components will be obtained and the following tests will be made at CEL:

A. Total solids
B. Percent pigment
C. Viscosity
D. Weight per gallon
E. Infrared analysis

5. Recording of air temperature, humidity, wind velocity, and general weather conditions during each phase of the construction.

INSTRUMENTATION: Thermocouple wire will be furnished by CEL and installed by CEL and Training Center personnel. Thermocouple test instrument and switching unit will be furnished by CEL and instruction in their operation will be given to Training Center personnel assigned to operate the equipment.

TEST MEASUREMENTS AND OBSERVATIONS: Thermocouple installations will be made at the locations shown on the accompanying sketch (see Figure 3). In each of the five sections having different coatings, temperature measurements will be made at the base of the foam and at the base of the coatings (top of foam) on the southerly slope of each section, where the most intense sunlight can be expected. Only the measurement at the base of the foam will be made on the northerly slope of each section. The prevailing outside air temperature will be measured at the location shown on the sketch (Figure 3). In addition, the ambient air temperature inside the buildings just beneath the roof will be obtained at four locations. Temperature measurements will be made at least twice each day, once in the morning and once in the afternoon. Periodic visual inspections will be made by Training Center personnel, and semiannual inspections and evaluations will be made by personnel of NORDIVNAVFAC/CEL for a minimum of 3 to 5 years, and thereafter annually as deemed appropriate. Photographs will be taken as required to properly document deterioration in any of the roofing systems. If adequate past records are available, comparisons will be made of the heating and cooling costs of the buildings to ascertain a monetary value for the improved insulation.

DOCUMENTATION: All observations and measurements made during the construction phase will be documented by CEL/NORDIVNAVFAC personnel. Training Center personnel will be furnished notebooks in which to log the daily temperature readings. At periodic intervals the log book will be sent to CEL for evaluation and study (another log book will be available for daily readings). Training Center personnel will also be asked to log in the books any peculiarity of the roofing systems observed visually. NORDIVNAVFAC/CEL personnel will also document results of their visual inspections.

Appendix B

PORTIONS OF
NAVFAC SPECIFICATION NO. 04-73-0272
ROOF REPAIRS AT
NAVAL RESERVE CENTER,
CLIFTON, NEW JERSEY

Note: The portion of the contract specification that follows was prepared specifically for this research project and should not be used for general procurement purposes.

SECTION 2 REMOVALS

2.1 General requirements: Removals shall be performed without damage to adjacent retained work; however, where such work is damaged, the contractor shall patch, repair or otherwise restore same to its original condition. All existing materials, fixtures, and equipment which have been removed or disconnected, but are not indicated or specified for reuse in the new work shall become the property of the contractor and shall be removed from the activity by the contractor at his expense.

2.2 The work includes removal of all old coating by sandblasting from roof.

2.3 Sandblasting of metal roof shall be performed using brushing stroke.

2.4 Special precautions shall be taken to insure that particles removed by sandblasting are not blown into open joint spaces in the metal deck.

2.5 Barricades and other safety precautions shall be taken to protect personnel and property in the work area. Additional precautions shall be taken as directed by the Officer in Charge of Construction.

SECTION 3 SPECIAL ROOF COATINGS

3.1 Applicable documents. The *following specifications* and standards of the issues listed in this paragraph (including the amendments, addenda, and errata designated), but referred to hereinafter by basic designation only, form a part of this specification to the extent required by the references thereto.

3.1.1 Federal Specification

SS-A-00701a (GSA-FSS)	Asphalt, petroleum (primer, roofing, and waterproofing)

3.2 General requirements. The work includes the provision of special roof coating systems as indicated. The roof surface shall be kept clear of traffic during, and for 24 hours after, completion of the work.

3.3 Materials.

3.3.1 Asphalt primer shall conform to specification SS-A-00701a.

3.3.2 Urethane foam shall be CPR 485-2.5 (2.5 pound density) as manufactured by CPR Division, Upjohn Company, and shall be applied by a contractor approved by the manufacturer of the foam.

3.3.3 Coating No. 1 shall be Silicone Weather Coating as manufactured by General Electric Company. The base coat shall be SCM 3308/501C medium grey and the top coat shall be SCM 3304/3007C cement grey. Ceramic granules SCM 3551 shall be applied to one-half of the roof section designated for coating No. 1 as indicated. The coating and granules shall be applied with equipment and by an applicator approved by General Electric Company.

3.3.4 Coating No. 2 shall be Silicone 3-5000 Construction Coating as manufactured by Dow Corning. The base coat shall be grey and the top coat shall be white. The coatings shall be applied with equipment and by an applicator approved by Dow Corning.

3.3.5 Coating No. 3 shall be Butyl-Hypalon as manufactured by U. S. Polymeric. The base coat shall be PC 8105, fire resistant black butyl rubber, and the top coat shall be PC 8204, white hypalon. The coating shall be applied with equipment and by an applicator approved by U. S. Polymeric.

3.3.6 Coating No. 4 shall be the Elastron No. 858 system manufactured by United Paint. The base coat shall be Elastron 858, a tan butyl rubber primer, and the top coat shall be Hypalon 35, a white hypalon. The coating shall be applied with equipment and by an applicator approved by United Paint.

3.3.7 Coating No. 5 shall be Monolar Mastic No. 60-36, a white hypalon system, manufactured by the Foster Division of Amchem. The coating shall be applied with equipment and by an applicator approved by Amchem.

3.3.8 Flashing, where indicated, shall be conventional fabric reinforcement as recommended by urethane foam manufacturer.

3.3.9 Materials other than those specified herein will not be acceptable.

3.4 Manufactured materials shall be delivered in manufacturers' original unopened containers with labels intact and legible. Where materials are covered by a referenced specification, the containers or packages shall bear the specification number, type, and class as applicable. Materials shall be delivered in sufficient quantity to allow continuity of work. Wet materials shall be marked and removed from the project site. Materials shall not be stored on the roof. Emulsions shall be stored in temperatures above 40 degrees F. Material handling equipment shall be selected and operated so as not to damage existing construction.

3.5 Environmental conditions. Application will not be permitted during inclement weather, when the roof surface temperature is above 120°F

or below 40°F, when the wind velocity is above 12 mph, when the relative humidity is above 80%RH, or when there is ice, frost, surface moisture, or visible dampness on the roof deck.

3.6 Surface preparation. All metal surfaces to receive urethane roofing system shall be sandblasted to remove all old coating, rust, dust, dirt, and other foreign materials, and shall be swept clean. Refasten any loose metal roofing and repair any areas where there are penetrations of the roof surface. Renail or repair any loose areas of the mineral-surfaced cap sheet over the passage building between the two metal buildings. Repair or replace with new any damaged flashings. Any grease, oil or other material that the urethane spray will not satisfactorily adhere to shall be removed. Finely divided spray particles may become a fire hazard; primers or top coats may contain flammable solvents. All normal fire precautions shall be taken. Slip sheets shall be installed at the junction between the mineral-surfaced cap sheet roofing and the metal roofing (in the area involving surface coating No. 4).

3.7 Installation. All materials furnished shall be applied in strict accordance with the manufacturer's printed instructions except as modified. The contractor shall assure that different coatings are compatible where they overlap.

3.7.1 Asphalt primer shall be applied to the entire roof surface at a rate of one gallon per 200 to 400 square feet, following proper cleaning procedures previously specified.

3.7.2 Urethane foam shall be uniformly applied to the entire surface following complete drying of the asphalt primer. The urethane foam shall be sprayed in place to a full thickness of 1-1/2 inches (+ 1/4,-0) in at least two (2) layers, with no layer being thicker than 3/4 inch. On any one day, no more roof surface shall be foamed than can be coated with a base protective coating on the same day. No foam shall be allowed to stand uncoated overnight. Foam shall be wrapped around overhanging roof edges to meet the vertical exterior walls of the buildings. The finished surface of the urethane foam, before protective coating is applied, shall be free of bumps, lumps, and ridges, and shall be smooth enough to receive the coating. An "orange peel" surface is acceptable; but no "popcorn" or "tree bark" surfaces will be accepted. "popcorn" or "tree bark" surfaces must be removed and reapplied at the contractor's expense. All spray equipment used for application of the foam shall be that recommended by the manufacturer of the foam, and the equipment shall be kept in suitable condition to assure proper application. The finished foam surface shall provide proper drainage with no ponding of water. Applicators shall be required to follow instructions in the "Guide for Safe Handling and Use of Urethane Foam Systems" as published by the Urethane Systems Manufacturers' Committee, Cellular Plastics Division, Society of the Plastics Industry.

3.7.3 Protective Coating Systems. The first coating application shall be made in the period 2 to 4 hours following set-up of the urethane foam. As with the foam, the coatings shall be wrapped around the overhanging roof edges to meet the vertical exterior walls of the buildings. On all protrusions through the roof, the coatings shall overlap the top end of the foam by at least two (2) inches onto the protrusions. Protective coating systems shall be applied the same day as the urethane foams in strict accordance with the manufacturers' printed instructions. Requirements of the individual coating systems are listed below. These application rates apply to a relatively smooth foam and are to be considered as absolute minimum. A foam surface with an "orange peel appearance" will require additional coating in order to obtain the required minimum dry film thickness. All base coats shall be free of dirt, dust, or contaminants and must be dry before application of the top coat. Any flaws in the base coat must be repaired before application of the top coat.

3.7.3.1 General Electric Silicone Weather Coating. Both the base coat (SCM 3308/501C) and the top coat (SCM 3304/3007C) shall be applied at the rate of 1 gallon per 100 square feet to provide a nominal wet film thickness of 16 mils and a nominal dry film thickness of 10 mils each. The topcoat shall be applied between 18 and 30 hours (preferably the following day) after application of the base coat; but in no case shall the top coat application start more than 72 hours after the base coat application. Total dry film thickness (base plus top coat) shall be at 20 mils minimum. On the half of the coating area to which ceramic granules are to be applied, the granules shall be applied at the rate of 50 pounds per square foot to the wet uncured top coat within 5 minutes after spray application of the top coat.

3.7.3.2 Dow Corning Silicone 3-5000. Both the base coat, 3-5000 (grey) and the top coat, 3-5000 (white), shall be applied at the rate of 1 gallon per 100 square feet to give a wet film thickness of 10 mils (dry film thickness of 7.5 mils) and a total minimum dry film thickness of 15 mils. The base coat shall cure between 6 and 24 hours before application of the top coat.

3.7.3.3 U.S. Polymeric Butyl-Hypalon. The base coat, PC 8105 (black butyl) shall be applied at the rate of 2 gallons per 100 square feet to provide a wet film thickness of 20 mils and a minimum dry film thickness of 10 mils. The base shall cure 4 to 6 hours, but not more than 24 hours, prior to application of the top coat. The top coat, PC 820 (white hypalon), shall be applied at the rate of 1-1/2 gallons per 100 square feet to provide a wet film thickness of 8-9 mils and a minimum dry film thickness of 5 mils. The total system minimum dry film thickness shall be 15 mils.

3.7.3.4 Elastron-United Paint. The base coat, Elastron 858 (tan butyl), shall be applied at a rate not less than 2-1/2 gallons per 100

square feet to provide a wet film thickness of 39 mils and a minimum dry film thickness of 18-1/2 mils. The top coat, Hypalon 35 (white) shall be applied at the rate of 1 gallon per 100 square feet to provide a wet film thickness of 12 mils and a minimum dry film thickness of 4 mils. The total minimum dry film thickness shall be 22-1/2 mils.

3.7.3.5 Amchem Foster Division, Monolar Mastic. The coating, Monolar Mastic 60-36 (white), shall be applied at the rate of 6 gallons per 100 square feet to provide a minimum wet film thickness of 90 mils and a minimum dry film thickness of 30 mils.

3.8 Protection of Adjacent Areas. The contractor shall protect adjacent areas from overspray of the materials by erecting a shield at the roof edges. This shield shall be tarpaulins or other similar material on suitable framing. The shielding method shall be approved before any spraying will be permitted.

3.9 Protection of personnel. Canister and cartridge masks capable of protection against isocyanate vapors and atomized particles shall be worn at all times by personnel spraying the materials.

3.10 Quality Control. The Quality Control provisions of Division 1, General Requirements, apply to this section. Approvals, except those required for field installations, field applications and field tests, shall be obtained before delivery of materials to the project site.

3.11 SUBMITTALS:

3.11.1 Certified Laboratory Test Reports: Before delivery of materials, certified copies, in triplicate, of the reports of all tests required in referenced publications shall be submitted to and approved by the Officer in Charge of Construction. The testing shall have been performed by an approved independent laboratory, within one year of submittal of reports for approval. Test reports on a previously tested material shall be accompanied by notarized certificates from the manufacturer certifying that the previously tested material is of the same type, quality, manufacturer, and make as that proposed for this project.

3.11.2 Certificates of Conformance or Compliance: Before delivery of materials, submit in triplicate notarized certificates from the manufacturer certifying that materials provided are chemically and physically compatible with each other and are suitable for inclusion within the total roof system specified herein. The acceptance of certification shall in no case jeopardize the Government's right to test materials when tests are deemed necessary to ensure compliance.

3.11.3 Descriptive Data: Before delivery of any materials to the building site, the following descriptive data shall be submitted to and approved by the Contracting Officer.

a. Roof coating materials (base and top coats)
b. Urethane foam
c. Applicating equipment

3.11.4 Samples: A 1-gallon sample of asphalt primer (SS-A-00701a) shall be furnished 30 days prior to start of work. The contractor shall also provide two (2) foot-square, 1/2-inch-thick plywood pieces for foam and coating samples at time of construction.

Philadelphia, Pennsylvania 7 June 1973
T. C. WILLIAMS, CAPTAIN, CEC, USN
Commanding Officer, Northern Division
Naval Facilities Engineering Command
(Officer in Charge of Construction)

Appendix C

MANUFACTURERS AND TRADE NAMES OF MATERIALS USED IN EXPERIMENTAL ROOFS

ITEM	MATERIAL	SOURCE
Urethane Foam	CPR-485 Components A & B	CPR Division, The Upjohn Company, 555 Alaska Ave, Torrance, CA 90503
System 1.	Silicone Weather Coatings SCM 3308/501C SCM 3304/3007C Granusils SCM 3551	Silicone Products Department, General Electric Company, Waterford, NY 12188
System 2.	3-5000 Construction Coating	Dow Corning Corporation, Midland, MI 48640
System 3.	PC 8105 PC 8204	U.S. Polymeric, 700 East Dyer Road, Santa Ana, CA 92707
System 4.	Monolar Mastic No. 60-36	Foster Division, Amchem Products, Inc., Ambler, PA 19002
System 5.	Elastron Number 858 Elastomir Hypalon #35	United Coatings 1130 E. Sprague, Spokane, WA 99202

DISTRIBUTION LIST

SNDL Code	No. of Activities	Total Copies	
–	1	12	Defense Documentation Center
FKAIC	1	10	Naval Facilities Engineering Command
FKNI	6	6	NAVFAC Engineering Field Divisions
FKN5	9	9	Public Works Centers
FA25	1	1	Public Works Center
–	6	6	RDT&E Liaison Officers at NAVFAC Engineering Field Divisions
–	305	309	CEL Special Distribution List No. 14 for persons and activities interested in reports on Shore Facilities